COURSE 3

Protect and Restore Natural Ecosystems and Limit Agricultural Land-Shifting

Increasing agricultural productivity and reducing the rate of growth in demand for agricultural products permit greater protection of ecosystems and their stored carbon. But these strategies alone are not sufficient. Course 3 focuses on the land management that needs to complement these efforts. One guiding principle is the need to make land-use decisions that enhance efficiency of both agriculture and ecosystem services. Another is the need to explicitly link efforts to boost agricultural yields with the protection of forests and other natural lands.

TABLE OF CONTENTS

Introduction

Holding down growth in food demand (Course 1) and boosting agricultural yields (Course 2) could prevent expansion of the net global area of agricultural land. In the case of our more ambitious scenarios, these two strategies could even lead to a decline in agricultural land area. But our calculations are based on the net need for agricultural land. Our model assumes that every hectare of land that is not converted because of reduced growth in demand (or increased yields on existing hectares) saves the carbon that would otherwise be released by converting that additional hectare. Unfortunately, the land-use challenge is more complicated than that. Even if net expansion of agriculture is eliminated, agricultural production will continue to shift from one place to another. These shifts often involve conversion of biologically diverse and carbon-rich habitats, which immediately releases long-stored carbon and harms biodiversity.

Although necessary to hold down net expansion of agricultural land, yield growth for some crops in tropical countries could even accelerate these shifts, by making farming more profitable and giving farmers an incentive to clear new land. Translating yield gains into full benefits in the real world therefore requires land management efforts that are designed to minimize gross—not just net—agricultural expansion and reduce the environmental costs of any expansion that does occur.

To achieve climate and ecosystem goals, some active restoration efforts are also required. Agricultural land that is abandoned—whether as a result of agriculture shifting to other locations or net declines in agricultural land area—tends to naturally regenerate into forests and other native habitats. However, active restoration could enhance benefits for carbon storage and other ecosystem services. Today, a limited amount of agricultural land is so marginal that it is incapable of generating higher yields in practice and warrants restoration right away. Little-used drained peatlands release so much carbon dioxide that they also deserve priority action.

CHAPTER 17

THE CAUSES AND CONSEQUENCES OF AGRICULTURAL LAND-SHIFTING

Agricultural land is not only expanding overall but also shifting its locations among and within regions and countries, which imposes environmental costs. This shifting is not to be confused with what is sometimes called "shifting" or "swidden" agriculture, in which farmers with few inputs engage in multiyear crop rotations, allowing exhausted fields to reforest before clearing them again.

Global and Regional Shifts in Locations of Agricultural Land

At the global level, agriculture is generally shifting from the North toward the South. Between 1961 and 2013, cropland declined by 126 million hectares (Mha) in Europe and North America but expanded by 331 Mha in Africa, Asia, Latin America, and Oceania.[1] As discussed in Chapter 10, pasture area is also shifting, declining by 66 Mha in Australia and New Zealand between 1994 and 2014 while expanding in Latin America.[2]

This trend is likely to continue because population and demand for food will increase more rapidly in developing countries. For example, using older UN population growth projections, the UN Food and Agriculture Organization (FAO) projected that cropland area would decline by 38 Mha in developed countries between 2006 and 2050 even as it expands by another 107 Mha in developing countries.[3] Using the GlobAgri-WRR model, we also project a shift in the global share of agricultural land. Because future trade is so difficult to estimate, we assume that the percentage of each food imported or exported will remain at the same levels as in 2010, which means the model does not allow a higher percentage of food consumed in developing countries to come from developed countries in the future. Even so, the model estimates that agricultural land will expand by an additional 474 Mha in developing countries but by only 119 Mha in developed countries (Table 17-1).[4] We believe that even this relatively small role for developed countries may be an overestimate because our baseline scenario probably does not fully capture the effects of increasing land-use competition in developed countries.

Table 17-1 | Projected change in agricultural land use by region, 2010–50 (baseline scenario)

REGION	CHANGE IN CROPLAND AREA (MHA)	CHANGE IN PASTURELAND AREA (MHA)	TOTAL CHANGE IN AGRICULTURAL AREA (MHA)
Asia (excluding China and India)	42	61	103
Brazil	2	34	37
China	-25	-1	-26
European Union	-17	8	-8
Former Soviet Union	0	-33	-33
India	32	2	34
Latin America (excluding Brazil)	12	68	80
Middle East and North Africa	8	10	18
OECD (other)	5	52	57
Sub-Saharan Africa	104	158	262
United States and Canada	27	43	70
Total	**192**	**401**	**593**

Note: Figures may not sum correctly due to rounding.
Source: GlobAgri-WRR model.

Gross versus net agricultural expansion

Many years of satellite image studies show that locations of agricultural land also shift substantially within regions.[5] Figure 17-1 shows an analysis by FAO based on satellite imagery of forest losses and gains by continent from 1990 to 2005. Although both Africa and South America had net losses of forest, these were substantially smaller than gross losses, which implies that agricultural land expansion in some places is outpacing reversion to forests on abandoned agricultural land elsewhere.[6] Asia, too, had large gross losses, particularly of native wet tropical forests. The continent experienced a net forest gain overall (nearly 50 Mha between 1990 and 2010), but this gain was largely due to establishment of tree plantations, particularly in China.[7]

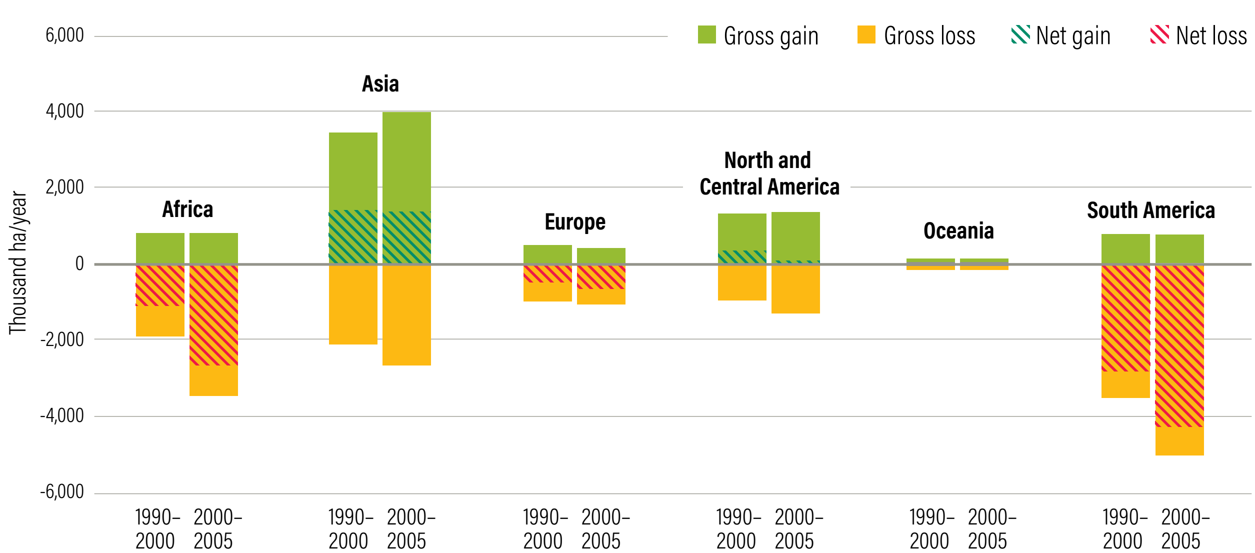
A separate study of deforestation in Latin America from 2001 to 2010 found that gross forest loss exceeded net forest loss by three to one (Figure 17-2). In the United States, 3 Mha were converted to cropland between 2008 and 2012, even as 1.8 Mha of cropland elsewhere in the country were abandoned or otherwise taken out of food production.[8] In Europe, one study found 1.6 Mha of agricultural expansion from 1990 to 2006, but 2.1 Mha of other agricultural land reverted to some kind of forest or other more natural vegetation.[9]

Although these shifts in the locations of agriculture permit some abandoned lands to regenerate, the trade-off tends to be poor from the perspective of biodiversity and carbon storage. New cropland is being established primarily in the tropics and subtropics, where biodiversity is much higher.[10] Many newly converted lands were formerly natural or relatively natural forests and grasslands,[11] whose biodiversity is often irreplaceable.[12]

Because conversion in the tropics often occurs on relatively intact native ecosystems, the carbon losses are often higher per hectare than conversion of agriculture in other parts of the world. It is at least as important to note that tropical yields also tend to be lower. As a result, the carbon storage lost per ton of crops produced is higher in the tropics than in the temperate and boreal zones.[13] Time also matters. The losses of carbon during land conversion mostly occur immediately, while restoring carbon in vegetation and soils occurs gradually over longer time periods.[14]

In addition, farmers tend to abandon land that is dry and at higher elevations, whereas they tend to clear wetter and more productive ecosystems, which tend to be richer in carbon and biodiversity.[15] Overall, gross land conversion caused by shifting locations of agricultural land presents a major environmental challenge that has received insufficient global attention.

Figure 17-1 | Gross forest losses are far greater than net forest losses because locations of agricultural lands are shifting



Source: FAO (2012a).

Figure 17-2 | While forests recovered in some areas of Latin America from 2001 to 2010, even larger areas were cleared elsewhere for agriculture

Source: Aide et al. (2012).

Drivers of Agricultural Land Expansion and Location Shifting

Several powerful forces are driving shifts in location of agricultural land, and they are likely to continue pushing expansion in many locations even if the total, global demand for agricultural land stabilizes. One important driver is high growth in demand for food in specific regions. Another is rising demand for specific food types that are best grown in the tropics. A third is the advance of roads and other infrastructure across the global South that is opening up new, financially cheap but environmentally expensive lands for agriculture.

Some regions face high growth in demand for food

In some countries or regions, the growth in food demand is likely to be so great that it will prove extremely difficult, if not impossible, to prevent some expansion of agricultural area.

Sub-Saharan Africa poses the greatest challenge, as explored in Box 2-4, because the likely growth in domestic food demand will make some expansion of agricultural land inevitable. Although we use FAO's predictions of robust yield growth in the region of roughly 250 percent between 2006 and 2050,[16] our baseline projection is that the region's cropland will nevertheless still expand between 2010 and 2050 by roughly 100 Mha. If we use less optimistic yield trends based on 1989–2008 rates—our "alternative baseline"—we project cropland expansion of 241 Mha.[17] These projections assume that the region continues to rely heavily on other countries for its staple foods, importing roughly 20 percent of meat and milk and 18 percent of cereals.[18]

Other analyses come to similar conclusions. One study found that even if countries in West Africa were able to more than double their rates of cereal yield gain between 2001 and 2014 (and triple their rates of maize yield growth) out to 2050, their imports of cereals would still have to grow from 21 percent to 45 percent by midcentury if they did not expand their cropland.[19] Actual self-sufficiency in maize would require yield growth of roughly 144 kilograms (kg) per hectare per year, which is five times the rates of yield gain from 2001 to 2014 in Africa and roughly 3.5 times the global average rate of yield growth. Some estimates indicate that for sub-Saharan Africa to become self-sufficient in crop calories, cereal yields would have to increase fourfold between 2007 and 2050. Using FAO 2050 yield estimates, crop area would have to grow by 140 Mha from 2006 to 2050 just to maintain roughly present levels of imports.[20]

Some regions will meet high international growth in demand for vegetable oil and animal feeds

The growing demand for vegetable oil and high-protein animal feeds, and the ability of tropical and subtropical countries to meet this demand well by producing palm oil and soybeans, represents another driver of gross land expansion in some countries and a likely shift of agricultural production to their lands.

Soybeans are inputs to both vegetable oils and animal feeds. Globally, soybeans were grown on 84 Mha in 2003 and 111 Mha in 2013,[21] a 33 percent increase over one decade despite advances in breeding and management of this heavily researched commodity crop. Other researchers have projected that even with yield gains, the global area dedicated to soybeans will need to increase by another 30 Mha by 2050 or even by 2030 to meet estimated demand.[22] Latin America is a good region for growing soybeans, with Brazil and Argentina already being two of the world's three principal producers. Even in Africa, where soybean yields to date have been low, vast areas have relatively high growth potential.[23] The economics of rising demand, relatively lower land costs in emerging and developing countries, and good yield potential will continue to drive expansion of soybean planting in these areas.

Continued growth in demand for palm oil will also place enormous pressures on tropical rain forests, which provide the best conditions for growing oil palm trees. With an average global yield of 3.7 tons of oil per hectare, oil palm generates seven times the oil yield per hectare of soybeans.[24] In 2015, oil palm provided 31 percent of the world's vegetable oil production by tonnage, even beating out soybeans (at 24 percent) as the world's dominant vegetable oil crop.[25] The 13 Mha of oil palm plantations around the world in 2011[26] are heavily concentrated in Indonesia and Malaysia, which together accounted for 85 percent of global palm oil supply in 2015.[27] But the industry is making inroads into West Africa, Central Africa, and South America.[28] Despite some efforts to curtail the use of palm oil,[29] experts predict that palm oil will meet an even larger share of future vegetable oil demand because of its high productivity and low cost. One estimate projects a need for at least an additional 12 Mha of oil palm plantations globally from 2009 through 2050 to meet worldwide demand—and potentially more.[30] And if palm oil production does not expand but vegetable oil demand continues to grow as projected, even more hectares of land would be converted to grow lower-yielding vegetable crops to meet projected demand.

The global South is developing its roads and other infrastructure

Agriculture is also expanding in many areas because of new roadbuilding. Studies have shown that new or improved roads into forests typically lead to large areas of deforestation and agriculture expansion along those roads.[31] In the Brazilian Amazon, for example, 95 percent of deforestation has occurred within 5.5 kilometers (km) of a road.[32] Not only do roads provide economic access to new areas but, over time, economic activity starts to grow, especially extractive and agricultural activities. Vested interests in further clearing and roadbuilding emerge. Large roads tend to lead to serial networks of smaller roads.

The environmental effects of roads go beyond direct land-clearing. Roads allow people to hunt wildlife and harvest timber illegally and create paths for invasive species.[33] Vehicles on roads kill large numbers of animals and pose particular problems for species that migrate over large areas.[34] Roads also encourage logging.[35] New roads are now penetrating many of the world's last remaining forest wildernesses, including the Amazon, Papua New Guinea, Siberia, and the Congo Basin.[36]

New roads present an enormous challenge to forests and other natural areas because roadbuilding also plays a major role in economic development generally and in the improvement of agriculture on existing croplands and pasture.[37] Poor roads increase the costs of inputs, decrease the prices farmers receive for outputs, increase food storage losses, and create significant additional uncertainties for investors. Many studies have shown that boosting yields of milk and of many crops is often not economical in the absence of good market access, which requires acceptable road networks.[38] The rutted, rural roads common in Africa, Latin America, and even much of Asia are therefore major impediments to agricultural improvement.

For these reasons, roads are often built through forests and other natural areas to spur economic development rather than (primarily) to open up new areas for farming. For example, roads may be constructed to connect cities or to increase access to ports: the purpose of a road paved through the Amazon forest from Mato Grosso in the south to Santarém on the Amazon River in the north was to make it less expensive to export soybeans and other crops from Mato Grosso, an already heavily developed agricultural state. But a side effect was to encourage additional deforestation along the road (Figure 17-3).[39]

Governments have extensive plans for roadbuilding, at different stages of realization, all over the world.[40] One study has documented 33 new or growing transportation and development corridors in sub-Saharan Africa, extending over 53,000 km. Ten of these roads are active, nine are proposed for upgrading, and 14 are planned.[41] The study found that the transportation networks (including a few railroads) would bisect 408 protected areas and 574 Mha of protected habitats, and that many would "promote serious and largely irreversible environmental change." Roadbuilding also appears to be getting a boost from international infrastructure funding. The G20 group of wealthy countries committed to double the current value of global infrastructure by 2030 by investing $60–70 trillion worldwide.[42] The addition of the Asian Infrastructure Investment Bank (AIIB) to the global multilateral bank scene in 2016 is likely to accelerate infrastructural investment. AIIB expects to double its lending within the next five years and to fund major infrastructural projects such as gas pipelines, railways, and motorways.[43] Realistically, if roadbuilding follows present plans, large-scale deforestation of intact old-growth forests is all but certain to occur.

Figure 17-3 | Roadbuilding has led to deforestation and agricultural expansion in Pará, Brazil

Source: Imagery © 2019 Landsat/Copernicus, Map data © 2019 Google.

The Potential of Yield Gains to Shift Locations of Agriculture

Because boosting global output per hectare is a mathematically necessary way to meet increases in food demand without land-use change, yield gains are a critical course on our menu. Unfortunately, yield gains can also accelerate shifting and local expansion of agricultural land, particularly in developing countries.[44] Initial studies struggled to explain this phenomenon and some even suggested that yield gains might increase not just local but even global land use for agriculture. But more recent research has pointed out that expansion occurs at the country level when increased yields lead to greater competitiveness and more exports.[45] In effect, yield gains do tend to reduce global agricultural land use if compared to the alternative of growth in demand without yield gains—but yield gains can also lead to increased agricultural area where those yield gains occur. It is important to appreciate why.

The "consumption rebound" effect?

One potential explanation is that boosting yields helps lower prices, and people respond by consuming more food—a consumption "rebound effect." If consumption increases by a larger percentage than yields, agriculture will expand into new lands. We consider this consumption effect to be generally a small and inappropriate concern.

First, the economic evidence is strong that, on balance, global yield gains will save land. For most foods, people only modestly increase their consumption of crops when prices decline.[46] As a result, a 1 percent decrease in price will generally cause substantially less than a 1 percent increase in consumption of crops. In addition, a 1 percent increase in crop yield by itself will cause less than a 1 percent decrease in crop price because land is only one cost of production and decreasing land cost by 1 percent does not decrease total costs by 1 percent. In addition, farmers may achieve higher yields by increasing other inputs, and therefore increasing their costs.[47] Putting these two effects together, although a 1 percent increase in yield by definition means a 1 percent decrease in land area to produce the same amount of food, it will in general cause less than a 1 percent increase in consumption and will therefore save land overall.

Second, a sustainable food future requires improving food availability for billions of poor people who spend large percentages of their income on food. Lower food prices help to meet their needs, and intentionally seeking higher prices than necessary is not morally acceptable. An alternative past with no Green Revolution would have included more hunger and less food consumption.[48] Increasing the capacity of the poor to consume food, in part by keeping food prices low, is one of the requirements for a sustainable food future.

Such an approach does not preclude use of prices to influence overconsumption by the wealthy, but that influence must occur through taxes. The consumption of the world's wealthy people is little affected by farmgate food prices for two reasons: price increases have less effect on their consumption, and farmgate prices are a small component of the retail food prices that people pay in developed countries.[49] Increases in farmgate food prices would therefore mainly affect the poor, and the only practical way to use prices to target consumption by the rich is through taxes at the retail level.

One exception may be yield gains for beef and other ruminant meats. These yield increases may not increase total food or total meat consumption, but they may cause consumers to consume more beef and less chicken or vegetable sources of protein. These dietary shifts would not benefit nutrition or the poor but would increase land-use demands and greenhouse gas (GHG) emissions. Studies also estimate that prices have a substantially larger effect on meat consumption than on other foods (sometimes with absolute elasticity values around 1, which means that a 10 percent decrease in price would result in a 10 percent increase in consumption).[50] Yield increases therefore do have some realistic potential to increase beef consumption. Increases in pasture yields still play a critical role in our menu for a sustainable food future, and it is hard to imagine a future scenario that freezes agricultural

land expansion without achieving vast increases in pasture yields. But if higher yields lead to lower prices, some compensating measures to avoid increased consumption of ruminant meat may also be necessary.

The "local production rebound" effect

The more important and environmentally challenging problem is what can be called a local production rebound effect.[51] Yield gains—even if they spare land globally—may encourage local conversion of forests, savannas, and other natural ecosystems by lowering local production costs. In other words, yield gains can improve the economics of farming per hectare, giving farmers incentives to put more hectares into production to increase their total profit. This pattern likely underpins expansion of soybeans, maize, and beef in Brazil and Argentina, and of oil palm in Indonesia and Malaysia.

This kind of locational shifting of agricultural lands does not occur because of yield gains per se. If all countries increased their yields in a way that lowered production costs by the same amount, no country would gain a competitive advantage.[52] The shifting occurs when yields increase and production costs decrease in some countries more quickly than in others. Countries where yields grow and costs decline more will be able to produce and export crops or livestock at lower prices and might therefore expand the land area dedicated to those commodities to meet increased internal and external demand.

This challenge does not mean that yield gains should be avoided because they risk encouraging local production rebound effects. In general, yield gains in North America and Europe are unlikely to trigger regional expansion of agricultural land because cropland area has been in long-term decline in these regions due to yield gains and stabilizing populations. If yield gains improve these regions' competitive advantage, that is likely to result only in maintaining more cropland in production. Even so, breeding that enables crops to grow in different locations can still cause land shifting in these regions; for example, breeding and development of crop varieties that can grow in drier, shorter growing seasons is likely a contributor to grassland conversion in the U.S. Great Plains.[53]

Failing to implement measures to boost yields in developing countries would be both morally unacceptable and foolish. It would be morally unacceptable because it would leave too many people dependent on farming at a disadvantage, and because relying on food imports is a risky strategy for poor countries.[54] It would also be foolish, in part, because not all drivers of yield gains will reduce costs of production and encourage local expansion. For example, protecting forests will force farmers to focus more on boosting yields through greater use of labor or technical inputs and will increase rather than decrease costs. More fundamentally, without yield gains poor countries with growing food demand are all but certain to expand their agricultural lands. Unless they increase yields, as African experience has shown, they will expand agricultural land area.[55] In addition, if no countries increase their yields, massive expansion of agricultural land is inevitable. Despite the risks of locational shifts of some agricultural land, failing to boost yields is a sure-lose strategy.

The only solution is both to boost yields and to use government policies where necessary to protect forests (and other natural ecosystems) and avoid shifting of locations of agricultural land. Private sector approaches that try to eliminate deforestation from their supply chains can also contribute. Although yield gains can pose risks, the challenge is to minimize the risks and harness yield gains for their positive outcomes.

CHAPTER 18

MENU ITEM: LINK PRODUCTIVITY GAINS WITH PROTECTION OF NATURAL ECOSYSTEMS

How can the world and farmers achieve the benefits of yield gains while also protecting natural landscapes? The heart of our answer is that efforts to achieve both need to be linked. The two goals of pursuing higher yields and protecting natural landscapes need to be linked by national and local governments, international funders, and private companies.

As part of this linkage, governments also need to develop integrated, spatially explicit, and evolving analytical systems to target roadbuilding and agricultural assistance where it can do the most good and avoid the most harm. This chapter starts by assessing whether governments can protect natural resources and how, then discusses the various methods for linking efforts to improve agricultural productivity with protection of natural landscapes.

How Governments Can Protect Natural Landscapes

Can governments protect natural landscapes? An extensive literature discusses the various available measures. The core lesson is that landscape protection presents great political and governance challenges but that governments have effective measures available to them to protect natural lands if they can mobilize the political will and master the governance.

Stop giving away public land for conversion

The most direct measure governments can use to protect natural landscapes from conversion is to stop giving this land away or selling it. The effects can be significant because, in much of the world, governments own the majority of natural land, and conversion occurs only when they grant the right to convert. In Indonesia, for example, the national government claims ownership of nearly all forest (subject to possible claims by Indigenous Peoples as a result of a Constitutional Court ruling).[56] This land can become available for agricultural development through reclassifications granted by the national forest agency on application by private companies.[57] By refusing to reclassify these lands, the national government can protect forest from agricultural conversion if it so chooses. However, both the national forestry ministry and regional land use authorities derive substantial revenues from land use concessions and transfers, which poses one of several political challenges faced by the government.[58]

In parts of Latin America, the "acquisitive prescription" doctrine has allowed those who clear public forest for farming to acquire ownership after a few years. Even though this claim to public land may be restricted to farms of a certain size, large landowners can subsequently come in and assemble large estates from the original claimants. In Colombia, for example, the principle of acquisitive prescription dates back to the original civil code. A 2002 law shortened the waiting period to acquire ownership from ten to five years after the forest has been converted to agricultural or similar productive use. One of the purposes of this legal doctrine is to prevent the possible injustice of a person abandoning land then returning to claim it after someone else has taken it over and put it to productive use. In Latin America, the principle was usually established to encourage conversion of natural lands to agricultural use. It allows seizure of government land and therefore allows people to claim ownership by clearing government-owned forest.[59] Changing such laws is fundamental to forest protection.

In Costa Rica and Brazil, changing laws on land titling so that people no longer acquire title to land by clearing it has played an important role in reducing deforestation.[60] Land titling laws can be effective in preventing conversion to cropland because such conversion involves substantial investment. If those who illegally convert fear that their claims to land ownership will not be recognized, and their future farm income jeopardized, experiences show that conversions will be reduced.

Unfortunately, although Brazil no longer promises legal title to those who deforest, it has a history of retroactively granting rights to those who illegally did so.[61] This encourages new cycles of illegal land-clearing. While governments can control how and where private parties may claim ownership or rights to develop public lands, in some cases they must attempt to strike a difficult balance between enforcement of land-use restrictions and the needs of impoverished smallholders.[62] Where farmers have clear title to their land, governments can combine enforcement with support for agricultural improvement on existing farmland to build social support.

Implement land-use restrictions

In the case of private lands or lands on which concessions have already been granted, there is no alternative but to pass laws restricting further conversion. Costa Rica, for example, passed a law in 1996 prohibiting further forest conversion. It has been mostly effective, if not perfectly enforced.[63] A study of productive lands in northern Costa Rica between 1996 and 2010 showed that the deforestation ban in 1996 cut in half the conversion of mature forest to cropland—in this case mostly pineapple and banana plantations.[64] In 2011, Indonesia imposed a moratorium on granting new agriculture and logging concessions in primary forests and peatlands.[65] Following the 2015 fires, the moratorium on opening peatlands was extended to cover areas already licensed but not yet developed.[66]

Establish protected natural areas

Although the mere designation of protected areas does not guarantee protection from deforestation, studies have generally found that such designations typically result in lower levels of deforestation. One global review found that areas of land designated as a protected area (e.g., national park, wilderness area, national monument) were consistently associated with lower levels of deforestation.[67] The study concluded that the efficacy of protected areas was probably a result of the heightened legal protection, remoteness, and/or poor agricultural potential.[68] The latter two features, however, highlight a requirement of future policy. Natural areas that might be good for agriculture are typically not chosen to become protected areas, but in some parts of the tropics it is these lands that are most at risk of deforestation. Going forward, therefore, an important strategy will be to establish a string of protected areas to block the path of agricultural expansion and thereby further encourage boosting yields on existing agricultural lands.

Establish and respect Indigenous Peoples' territories

Establishing protected lands for Indigenous Peoples, and respecting their integrity, in addition to recognizing the legitimate claims of such people to the land, also often leads to low levels of deforestation.[69] The conservation of forests in Indigenous Territories in the Xingu watershed of Brazil is a well-documented case where tribes guard the forests against illegal loggers, miners, and other intruders while forests continue to be cleared outside the territories. Community titling of indigenous lands appears to have significantly reduced both forest clearing and disturbance in the Peruvian Amazon.[70]

Enforce the law

The above measures work well only if they are combined with consistent enforcement.[71] Law enforcement can take the form of fines for illegal clearing, seizure of illegally converted lands, evictions of illegal squatters, and arrests of illegal ranchers. Three features could help make enforcement credible and politically supported over the long term. First, the "stick" of law enforcement should be complemented with the "carrot" of positive economic incentives for those people who might be most affected. Second, law enforcement needs to avoid being unjust or repressive toward marginal communities, either in reality or in perception. Third, law enforcement needs to be fair; it should not selectively go after the poor while letting the rich and politically powerful go untouched.[72]

Increase transparency of land use and land-cover change

All the approaches to protecting natural ecosystems listed above benefit from adequate spatial monitoring which can detect adherence to and violations of the law and land designations. "Radical transparency" made possible by modern-day monitoring technologies (e.g., satellites, drones, cloud computing, the internet) can be a powerful foundation for accountability and enforceability. Global Forest Watch now has several satellite-based monitoring systems on its platform, capable of detecting the felling of trees at high spatial and temporal resolutions and combining those data with maps of protected areas, indigenous reserves, moratorium boundaries, extractive industry concessions, and more.[73] What is needed next are systems that can detect clearing of any form of natural ecosystem vegetation (beyond forests) since it is not just forests that are being converted to agriculture.

Of course, any one of these measures alone will be insufficient; it is the combination that has impact. Brazil illustrates this potential. The country has long had laws restricting the percentage of land on any farm that may be cleared (the "Forest Code"), yet enforcement lagged. Beginning around 2005, however, Brazil moved to enforce these laws, particularly in the Amazon, resulting in large reductions in deforestation rates, all while agricultural production continued to increase. Brazil reorganized its police enforcement and took actions against corruption. The country started using satellite monitoring (e.g., DETER and PRODES systems) to identify illegal deforestation in the Brazilian Amazon.[74] The country established new protected areas in the "arc of deforestation." Perhaps most creatively, Brazil identified municipalities where deforestation was most acute and put them on a "black list" for receiving public finance and rural agricultural credit (more on this form of "linking" protection and production below).

Linking Productivity Gains and Natural Landscape Protection

Although governments have mechanisms they can use effectively to protect natural landscapes, there are several reasons why explicitly linking such mechanisms with efforts to boost production on existing agricultural land is probably necessary both practically and politically to achieve this protection:

- **Linkage can help ensure that land protection does not undercut food production.** It will be nearly impossible to protect natural areas if yields do not grow on existing agricultural land because the unsatisfied demand for food will push up prices and increase food insecurity.[75] Not only is such a result unacceptable in and of itself, but it also would likely undermine political support for land conservation and increase the incentive for some agricultural interests to circumvent legal protections.

- **Linkage can help equitably share the burden of climate reductions.** Many relatively poor countries are currently significant sources of land-use change emissions but have small overall per capita GHG emissions. At the same time, the economies of many poor countries are heavily dependent on agriculture, and these countries face rising food needs. For them, global equity considerations require the international community to support their agricultural development on existing land in return for protecting their remaining natural landscapes.

- **Linkage can help sustain domestic political support for both goals.** Agricultural sectors that drive deforestation and other land-use change often have substantial political influence. Linking preservation of natural landscapes with strategies to increase agricultural productivity may be politically necessary at the national level to assure both national governments and agricultural sectors that agriculture can continue to prosper.

We propose three approaches to achieving such linkages:

- **Finance:** Structure domestic and international financing to simultaneously support yield gains and natural ecosystem protection and/or restoration.

- **Land-use planning:** Develop and use "living" analytical tools in the form of detailed land-use plans that prioritize areas for agricultural yield enhancement (including "climate-smart" road networks and other public infrastructure) and protect natural ecosystems.

- **Conversion-free supply chains:** Mobilize buyers, traders, and financiers of agricultural commodities to purchase or finance only commodities not linked to deforestation or other ecosystem conversions.

Finance

Domestic and international sources of finance offer avenues for linking yield enhancements with natural ecosystem conservation.

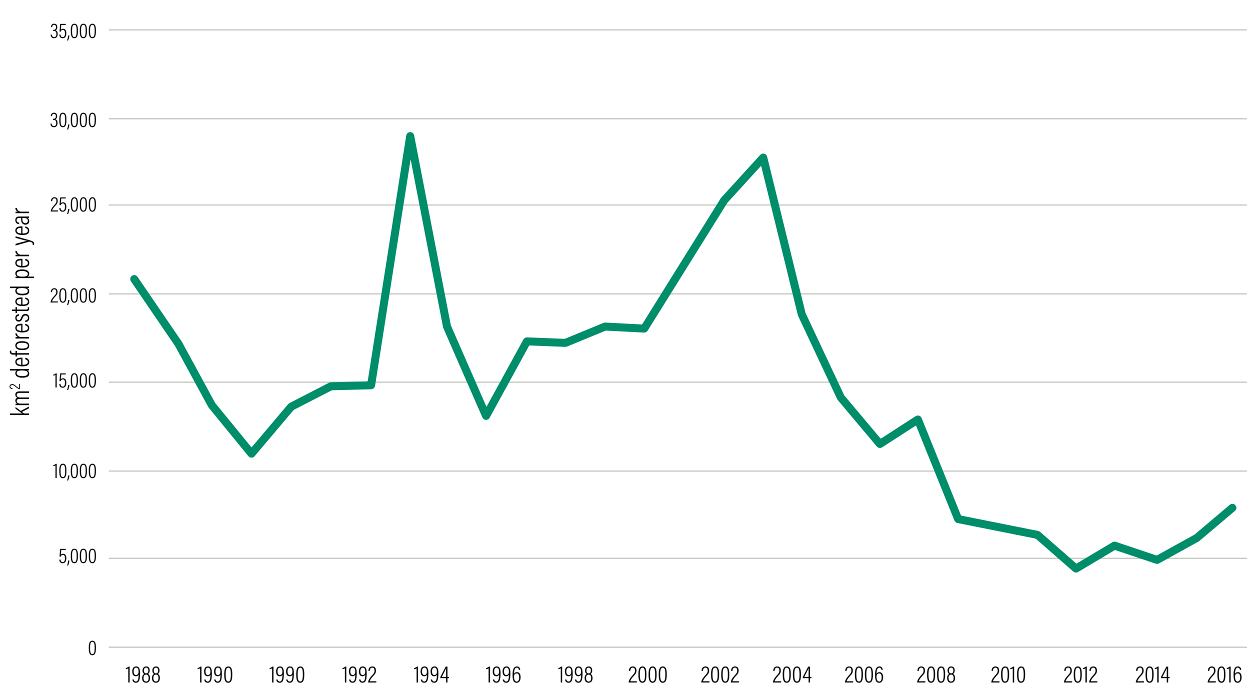
Domestic finance

Domestic sources of agricultural finance (e.g., national development banks, private banks) often help farmers and ranchers by providing low interest loans. To make the linkage, these loans could set eligibility conditions that preclude farmers and ranchers from converting forests or other natural ecosystems. Such lending conditions could be retrospective, wherein the bank assesses natural ecosystem clearing on the farmer's or rancher's land in the past. If there has been clearing after a certain year, the landholder is not eligible for a loan. Alternatively, the conditions could be prospective, wherein the farmer or rancher incurs a penalty (e.g., higher interest rate, hefty fine, loan call back) if he or she clears a natural ecosystem after receipt of the loan. Such conditioned loans would incentivize the landholder to invest in improving yields on his or her existing agricultural fields instead of clearing more land.

The Brazilian Amazon provides a successful illustration.[76] Rural credit supplies about 30 percent of the annual financing of farmers and ranchers in Brazil, and thus can be a powerful lever for behavior change. In 2008, the Brazilian National Monetary Council introduced Resolution 3,545, which conditioned rural credit in the Amazon biome on proof of a farmer's or rancher's compliance with legal and environmental regulations. One of these regulations was a limit on the amount of forest that a landholder could legally clear (20 percent of one's land). As a result, the amount of deforestation declined. According to one estimate, in the absence of the conditioned credit, deforestation rates in the Brazilian Amazon would have been 18 percent higher than actually observed in the 2009 through 2011 period.[77]

This linkage has also been important to maintaining political support for Brazil's forest protection, which has played a key role in reducing deforestation rates from their peak in 2004 (though rates have recently risen again) (Figure 18-1).[78] Work by EMBRAPA, Brazil's national agricultural research institution, helped demonstrate the capacity of Brazilian agriculture to continue to grow by boosting yields without clearing more land.[79] Brazil then explicitly linked its proposals to strengthen forest protection with additional incentives for agricultural intensification, both in its 2004 action plan for forest protection and its follow-up "ABC" climate plan in 2009.[80]

Figure 18-1 | Deforestation in the Brazilian Amazon has receded from historical highs



Source: Brazilian National Space Research Institute (INPE).

International finance

Developed countries have committed to providing billions of dollars to developing countries to help them mitigate and adapt to climate change—although only some of these funds have started to flow. But the funding for forest protection and for agricultural improvement tend to come through different channels. The World Bank, for instance, develops climate or environmental projects to protect forests and separately develops projects to boost agriculture productivity. Some countries provide funds for forest protection under the banner of REDD+ (Reduced Emissions from Deforestation and Forest Degradation in Developing Countries). At the same time, some countries provide funds for agricultural development. The link between agricultural improvement and natural ecosystem protection is rarely drawn.

This should, and can, be rectified. The main reason is to increase the likelihood of meeting both food production and forest protection needs, and preventing the needs of one from undermining the other. Linkages also would offer benefits to the key players. For example, international funders, mainly richer countries, would see their funds advancing two goals—poverty alleviation and climate protection. National governments would be able to make a more powerful case for financial support by achieving multiple objectives at once. And agricultural interests, whether big or small farmers, would improve production on their existing land while avoiding the risks of forest conversion.

Overall, there is a strong global, shared public interest in improving agricultural productivity in developing countries so long as that productivity helps protect forests. If funds are effectively linked, they can make the case for more funding, and they can provide benefits for agricultural interests that might otherwise resist forest protection.

Land-use planning

Land-use planning is a policy tool that governments can use to concentrate agricultural production in certain, high-yielding areas while designating natural areas as protected from conversion. To achieve this goal, land-use plans will need to be specific (geospatially and more), “living,” and cover development of road and related infrastructure.

Plans need to be specific

We believe effective land-use planning tools need to have multiple features, including the ability to achieve the following objectives:

- Characterize the location of existing production systems in as much detail as practicable to support technical and economic assessments of their potential for boosting yields.
- Apply at the local level, but aggregate production, emissions and land-use data to the regional and national level to allow assessments of national achievement.
- Identify the technical opportunities for sustainable agriculture intensification on existing agricultural lands.
- Provide analyses of the economic feasibility of improvement options for different types of farms.
- Identify the location of priority areas for sustainable intensification, and areas that must be preserved or restored.
- Identify the location of lower opportunity-cost lands when there is an unavoidable need for agricultural expansion (as discussed in Chapter 19).

Plans at this level of detail could serve many purposes:

- Guide public policies as well as public and private funders on where to invest.
- Reassure agricultural producers of their potential to increase production without clearing new lands.
- Quantify impacts on GHG emissions, including from land-use change, and how they would change with various improvements to agricultural development.
- Provide a technical basis for specific international agreements as well as domestic and international funding.
- Inform private sector and civil society priorities.

Plans need to be "living"

Such comprehensive planning tools will require detailed but evolving technical tools—not merely one-time maps and plans. Any immediate effort to develop these kinds of systems will meet resource constraints and data limitations and rely on models, such as crop models, that are imperfect. If people are to have faith in such efforts, the systems employed must be able to easily incorporate new, improved, and more detailed information as it becomes available. For such planning systems to work, they must therefore be reflected in computer-based programs that are continually updated and modified.

Supporting development of such plans should be a major concern of international institutions focused on either agriculture or climate, such as the World Bank. They should be a particular priority, as we describe in the next chapter, where agricultural expansion is inevitable, and we offer more detailed recommendations for funding such plans in that chapter.

Plans need to address roads and other infrastructure

A key use of such plans should be to identify where to build, rehabilitate, or improve roads and where to place other agriculture-related infrastructure. The only hope for reconciling the need for new roads for agricultural development in developing countries with protection of natural areas is to plan and build "climate-smart" road systems—systems that avoid incursion into remaining natural ecosystems while enhancing the ability of the agricultural sector to access markets.

Climate-smart road systems primarily involve focusing road improvements in existing agricultural areas, particularly where there is high potential for agricultural improvement. A recent study identified some priority areas at the global level for both road-building and avoiding road construction based primarily on climate-smart principles.[81] It and other studies have found, for example, areas of Africa with very poor roads that could reap great benefits from merely improving existing roads (e.g., paving dirt roads), not necessarily adding major new ones.

Such an approach would support high agricultural yields, keep transportation costs low, and contribute greatly to preservation of both carbon stocks and biodiversity.[82]

In general, this planning approach should be undertaken at high resolution at national and subnational levels and then incorporated into government land-use and infrastructure plans. It should be a prerequisite for international funding of road improvements.

Conversion-free supply chains

Buyers, traders, and financiers of agricultural commodities can choose to purchase or finance only commodities not linked to deforestation or conversion of other natural ecosystems. Conversion-free purchasing policies have the potential to persuade farmers, agricultural companies, and even political jurisdictions (e.g., districts, states) to meet growing demand by boosting yields instead of by expanding agricultural area. Otherwise, these farmers, agricultural suppliers, and jurisdictions would risk losing business customers, market access, and finance.

The most notable deforestation-free supply chain commitment is that of the Consumer Goods Forum (CGF). The CGF now comprises 400 of the world's leading consumer goods manufacturers and retailers from 70 countries, with combined annual sales of €2.5 trillion (about $2.8 trillion). In 2010, the board of the CGF committed to achieving zero net deforestation in supply chains for four commodities by 2020 and to curtail procurement from suppliers who do not comply. These commitments cover the agricultural commodities of palm oil, beef, soy, and pulp and paper. The impact of these pledges is trickling upstream. For example, major traders of palm oil have made similar pledges to buy and sell only deforestation-free palm oil. Getting major traders involved could help ensure that the supply chain pressure reaches markets where the CGF may not have as much influence, such as palm oil for home cooking in some Asian countries. As of late 2016, more than half the companies that source palm oil and wood products had made "zero deforestation" commitments, as well as 21 percent of companies that source soy and 12 percent that source beef.[83] The CGF could also reach small to medium-sized farmers or grower companies—which are not publicly visible and do not have robust sustainability commitments—if companies applied their commitment not only to their direct suppliers but also to their suppliers' suppliers.[84]

Financiers of agricultural commodities are taking steps, too. A number of banks have agreed to a Soft Commodities Compact designed to support business customers in their efforts to reduce commodity-driven forest conversion.[85] The compact commits banks to work with consumer goods companies and their supply chains to develop appropriate financing solutions that support the growth of markets producing palm oil, soy, and beef without contributing to deforestation. Twelve banks had adopted the compact as of January 2019.[86]

Voluntary actions by private corporations, in part motivated by civil society campaigns, will have their greatest effect when they reach a scale sufficient to influence an entire industry and motivate national legislators. In the mid-2000s, Greenpeace launched an effort to pressure European companies not to purchase soybeans from Brazil because of deforestation. These pressures helped lead to a commitment by the Brazilian Vegetable Oils Industry Association and the National Grain Exporters Association to establish a moratorium on the production and trade of soybeans grown on lands in the Brazilian Amazon that are deforested after July 24, 2006.[87] International agricultural traders such as Cargill and Bunge played an important role. The moratorium has been quite effective in the Brazilian Amazon. In the two years before the moratorium, 30 percent of soy expansion in the Brazilian Amazon occurred on newly deforested land. Since the moratorium, the share dropped to about 1 percent; almost all of the 1.3 Mha of new soy plantings from 2006 to 2013 in the region were on previously cleared lands.[88] One study showed that the moratorium is protecting lands that could otherwise be legally converted.[89]

At the same time, the moratorium did not undermine Brazil's soybean industry. Since implementation, soy production has continued to grow, mostly through intensification.[90] Nonetheless, some expansion of soybean area has occurred in the Brazilian Cerrado and the Bolivian Amazon. This leakage indicates that private efforts will be most useful only when they reach a scale large enough to motivate government policies as well.

To realize its potential, the conversion-free supply chain model needs more companies and financial institutions to make conversion-free supply chain commitments so that together they account for a significant share of market demand (or financing) of each agricultural commodity. Otherwise there is a risk of sizeable market "leakage," whereby suppliers merely divert deforestation-linked agricultural commodities to a large market of buyers that have not made commitments. Companies and banks also need to follow through on their commitments. And follow-through requires monitoring and accountability mechanisms.[91] Given that commitments for 2020 will likely not be met, how the CGF and other industry players respond and adjust their strategies will be critical to the future success of this approach.

"Jurisdictional" approaches

A potentially potent way of implementing these three approaches is to operate at the jurisdictional scale. The "jurisdictional approach" refers to a comprehensive approach to land-use governance, decision-making, and zoning across a legally defined jurisdiction (e.g., state, district) or territory.[92] Part of the theory of change is that those jurisdictions that succeed in implementing these approaches—and thus succeed in decoupling agriculture from ecosystem conversion—would start to receive preferential investment by companies and financial institutions. For example, they could be considered "low-risk" sources of supply or safe places for investment for companies making forest protection commitments. Other jurisdictions might observe these benefits and start to shift themselves. Examples are beginning to emerge. Launched at the Conference of the Parties (COP) 21 climate conference in Paris in 2015, the Brazilian state of Mato Grosso's "Produce, Conserve, and Include" strategy and plan aims to promote sustainable agriculture, eliminate illegal deforestation, and reduce GHG emissions—all at the same time. Responding to concerns about losing access to international soybean markets, it has 21 performance targets and involves 40 partner organizations. Currently, deforestation remains relatively low while the agriculture sector in Mato Grosso, led by soybeans, thrives.[93]

Produce, protect, and prosper

The underlying strategy of this chapter can be summarized as one of "produce, protect, and prosper." To achieve a sustainable food future, protection of forests and other ecosystems must occur at the same time as enhancements in crop and livestock yields. In addition to linking production and protection, people will need to "prosper" through the growth of their local economies; increased security of food, feed, and fiber; and reductions in poverty through job and income growth. Without such benefits, political support for sustainable intensification and for conserving natural areas might be lost over time.

CHAPTER 19

MENU ITEM: LIMIT INEVITABLE CROPLAND EXPANSION TO LANDS WITH LOW ENVIRONMENTAL OPPORTUNITY COSTS

Although the goal should be to avoid all agricultural expansion, in some locations agricultural expansion is inevitable. As discussed in Chapter 17, agricultural land will expand for local food production in much of Africa, for example, and oil palm plantations will expand in Southeast Asia. In these situations, the land-use plans we described in Chapter 18 need to guide where this expansion should go. How should they do so?

The Challenge

How should we define low opportunity-cost lands?

We begin by focusing on our disagreements with some previous analyses which claim that many broad categories of land should be viewed as either "free" to use or involve little carbon cost, typically because they are not existing cropland or dense forest, or because they are forests that have recently been cut. The errors generally track those discussed in Chapter 7 regarding bioenergy, which similarly assume that these categories of land are available to grow biomass crops at no or little cost in carbon storage or food production and with low or no social opportunity costs. Examples include *abandoned agricultural land*, which is not free because it would typically regenerate to forest or other natural vegetation; *pasture land*, which both stores carbon and produces food; *woody savannas*, which store abundant carbon and tend to have high biodiversity; and *cut-over forests*, which also regenerate if left alone or replanted.

A surprising number of studies refer to the potential to expand bioenergy or crop production onto lands they term "marginal" or "degraded."[94] Unfortunately, as well summarized by Gibbs and Salmon (2015), these terms have no precise meaning. Studies that use them offer multiple definitions but none that identify unused categories of land. These terms are frequently applied to lands that are considered marginal for cropping—but this quality does not make them marginal for purposes such as carbon storage or pasture.[95] Quite often, the terms are applied to lands already in agricultural use but typically experiencing some form of soil degradation. Their reclamation can and should be part of the effort to increase crop and pasture yields. They cannot provide lower opportunity-cost lands for agricultural expansion for the obvious reason that they are already in agricultural production. Even lands that are so unproductive that they store little carbon and produce low yields—and therefore are not good candidates for expanding agriculture anyway—are often extensively used by the poor.[96] The problem in each case is failing to recognize that virtually all land has some kind of opportunity cost.

The opportunity

The goal is to find lands with relatively low environmental and other opportunity costs but with good productive potential on which to expand agriculture. Several principles guide the search:

- Because these opportunities are a matter of degree, a proper analysis requires far more subtle evaluation than simply assessing broadly defined land-use categories and incorporating potential food yields.

- To reflect carbon effects, the analysis must account not just for existing carbon but also for likely future carbon sequestration (e.g., from regrowing forests on abandoned agricultural land or in forest areas that have been recently harvested for wood). Each year globally, regeneration replenishes most of all annual carbon losses from forest clearing and therefore plays a fundamental role in slowing climate change.[97]

- The analysis must focus not just on the loss of carbon per hectare but also on the loss of carbon per ton of crop that would likely be produced, which in turn depends on the likely yields.[98] Land may store little carbon, but if it will also produce few crops, farmers will need to clear more land and release more total carbon to produce the same amount of food.

Several studies support the hypothesis that targeting specific lands can meet food needs with lower environmental costs than using other lands. In Tanzania, one study looked at multiple criteria in addition to potential yield when considering areas for agricultural investment. Ideal areas for agricultural expansion varied depending upon whether the criteria included social capital, forest conservation, and farm management. Sometimes the use of different criteria led to conflicting answers.[99]

A second study focusing on Zambia found good results from a "compromise" approach giving equal weight to maximizing potential yield, minimizing transportation costs, minimizing carbon releases, and minimizing impacts on biodiversity. Such an approach reduced the potential transportation, carbon, and biodiversity costs by 80 percent while reducing the average potential yield of each new hectare by only 6 percent, compared to a strategy that focused on yield-enhancement alone.[100] This same paper showed that the "farm blocks" of land formally designated for agricultural expansion by the government were poor choices to achieve any of these four objectives.

Studies of this type recognize that land has different potentials. In general, wetter lands are more productive and better at producing crops, but they also store more carbon and support more biodiversity. Yet the relationship is not perfect. Rainfall patterns and soil types may reduce the productivity of crops more than of trees and therefore forests. Access to transportation and other infrastructure may make it more profitable to farm in one location than in another with higher, raw crop potential. Both carbon storage and biodiversity are undermined on lands with a history of human alteration. The biodiversity of any one hectare of land also depends heavily on the lands around it. If the only goal were agricultural profitability or productivity, these environmental considerations would be irrelevant. But if the goal is to achieve a sustainable food future, considering the wider advantages and disadvantages of farming different hectares of land opens up the potential to find options that are still beneficial to agricultural productivity and profitability while reducing environmental effects.

Indonesia has been a major focus of study because expansion of oil palm plantations into forests and peatlands has been occuring rapidly and because growth in global demand for vegetable oil makes some continued expansion of oil palm inevitable. One study estimated that optimal location of new oil palm plantations to double Indonesia palm oil production between 2010 and 2020 could avoid all primary and secondary forest loss. This outcome could avoid all biodiversity effects analyzed in the study, cut land-use change emissions by 30 percent, and reduce loss of other food production by two-thirds compared to the most likely "business-as-usual" scenario.[101] Ideally, farming would expand only into areas that have truly low environmental and social opportunity costs yet could still be productive croplands. To the extent that such lands exist, they will generally be lands that receive enough rainfall to be productive but face some kind of biological and physical barrier to significant natural regeneration.

One category of such low opportunity-cost, potentially productive land includes areas in Southeast Asia that were once logged or farmed then abandoned, and overrun by *Imperata* grasses. *Imperata* grasses store only modest quantities of carbon and will sequester little future carbon so long as they remain subject to frequent fire.[102] They also support far less biodiversity than forests[103] and are of poor quality for livestock, which leaves them with limited economic benefits. And the return on investment from establishing oil palm on converted *Imperata* grasslands can be favorable even when compared with the return on investment of establishing oil palm on recently cleared forests.[104] These lands are not truly free of opportunity costs: many occur in mosaics with some tree cover and some agriculture by smallholders. This is probably why they are burned. Even the densest *Imperata* stands could be replanted as forests but their use for oil palm would be appropriate because the alternative would likely be clearing of valuable primary or secondary forests. Although no one really knows how much *Imperata* grassland there is, estimates include 3.5 Mha[105] in Kalimantan and 8 Mha in all of Indonesia.[106] In theory, this area could provide most if not all of the additional expansion needed in Indonesia for another decade.[107]

In the real world, other factors also play an important role, including transportation access and social and legal acceptance (Box 19-1). These barriers are at least potentially subject to change with appropriate investments, zoning changes, incentives, and community outreach.

BOX 19-1 | Mapping lands suitable for sustainable oil palm expansion in Indonesia

Over the past several years, WRI has been working with Indonesian partners from government, industry, nongovernmental organizations, and research organizations to identify lands with lower environmental opportunity costs that have the potential to support sustainable oil palm plantation expansion in Indonesia.

In this mapping effort, we use an environmental suitability screen to filter out lands that, if converted to crops, would have large environmental costs in terms of carbon and/or biodiversity. In particular, it screens out all primary and secondary forests, swamps, peat soils of any depth, conservation lands and bodies of water, and their buffer zones. It also screens out human settlements, some agricultural lands,[a] aquaculture ponds, airports, and other large infrastructure. Figure 19-1 (left) shows the results of applying this screen to Kalimantan, Indonesia (on the island of Borneo).

Because not all the lands that pass the initial screening will be suitable for oil palm, the method layers on additional screens. The economic viability screen identifies those areas with appropriate elevation, slope, rainfall, soil depth, soil type, soil drainage, and soil acidity for an oil palm plantation to be profitable. Areas not meeting these criteria are eliminated from the map. Figure 19-1 (center) shows the results of layering in the economic screen.

The method then layers on a legal availability screen that factors in land-use zoning and community rights. Lands located in areas not zoned for agriculture can be difficult, but not impossible,[b] to convert into oil palm or other crops. Figure 19-1 (right) shows the results of layering on the legal availability screen for Indonesia.

Finally, for the areas that remain, a social acceptability screen discerns—via field-based stakeholder engagement and workshops—the interest and willingness of communities that live in and around a candidate site to have oil palm developed there. WRI's experience is that some communities support oil palm development while others do not.

As is evident from these figures, although the area of opportunity may seem large at first; the amount of land that remains practically possible for conversion to crops (in this case oil palm) is smaller after incorporating important parameters such as economic, legal, and social factors.

The lands that meet environmental criteria are not necessarily low-cost: most of these lands would reforest if not used by people, and human uses may produce a range of small-scale agricultural products. In the face of the world's fast-growing demand for vegetable oil, however, focusing oil palm expansion on these lands constitutes a vast improvement over alternatives that directly convert valuable natural forests.

For more details about this method, see Gingold et al. (2012).

Notes:

a. The method screens out existing plantations and intensively used agricultural areas according to Ministry of Forestry land cover data. To more precisely fit the definition of lands with low environmental opportunity costs suitable for cropland *expansion*, the method should screen out *all* active cropping areas, which must be determined via field surveys.

b. It would require having the relevant zoning agency (or agencies) rezone the tract of land into a class that allows for agriculture.

Figure 19-1 | Screening out lands that do not meet environmental, economic, and legal criteria reduces the area of land suitable for oil palm expansion in Kalimantan, Indonesia

Lands meeting the environmental criteria for supporting sustainable oil palm

Lands meeting the environmental and economic criteria for supporting sustainable oil palm

Lands meeting the environmental, economic, and legal criteria for supporting sustainable oil palm

Not suitable   Suitable

Source: Gingold et al. (2012).

Recommended Strategies

Where agricultural land expansion is inevitable, selecting areas for expansion that have relatively low environmental opportunity costs is one part of the effort we describe in this course to link yield improvements and protection of natural areas. But how can governments best identify such expansion areas?

Our main additional recommendation in this menu item is for governments to develop the kinds of land-use modeling tools we describe in studies for Indonesia, Tanzania, and Zambia to identify where inevitable land expansion should take place. Such tools will have to assess yield potential, likely costs of production, and carbon and biodiversity effects. International institutions such as the World Bank should help fund them. Several aspects of this challenge merit emphasis.

Quick results. Because different stakeholders have different interests, a tool must quickly show the results of different compromises. Individuals and groups are more likely to find common ground if they can see outcomes and decide whether they are acceptable. The Zambia model discussed above has this kind of feature to allow stakeholders to see easily the consequences of assigning different levels of importance to different goals.

Intuitive presentation of outcomes. Planning tools must overcome many technical challenges. There are many data limitations, and some goals are difficult to measure because they are so complex. Biodiversity will always remain a challenge to express in one simple unit because it may be valued in many different ways. For example, analyses may focus on the total number of species using an area of land, or they may focus only on threatened species, or on different taxa (such as vertebrates or categories of vertebrates), or they may identify areas based on loss of similar habitat types. Quantitatively, each objective can be measured using different units (e.g., units of carbon, biodiversity, and profitability), which are not directly comparable. Different methods of quantification will have different results, such as ranking areas by percentile or by absolute quantities. A useful planning tool needs to present outcomes for each scenario in units that make intuitive sense to people as far as is practicable, for example, in tons of crops per hectare, dollars of profit (if economic analysis is included in the model), and tons of carbon released. Not all modeling approaches are equally good.

Adequate funding. To develop and maintain a proper land-planning tool, dedicated resources are required. To focus on just one important input, estimating potential crop yield requires use of some kind of crop model. Good crop modeling requires a great deal of data, such as detailed soil data, which is typically not available broadly for all locations, and some of which may not be completely available in any location. Funds needed to be spent to make the data as accurate as possible.

Monitoring and updating. Resources must also be dedicated to determine whether predictions prove accurate, to reprogram the tools as necessary, and to update results as the world changes. Monitoring, recalibrating, and updating are not a one-time exercise but must be continued over time to ensure that predictions remain accurate.

Policymakers tend to be in a rush and often want results with limited resources. Because modelers can always make broad assumptions if necessary, they can generate models that look misleadingly convincing but that lack the rigor necessary to justify their use for important decisions. These kinds of mapping enterprises at the national level will require ongoing budgets in the low millions, not hundreds of thousands, of dollars. These efforts are not easy, but there is also no alternative if the goal is to achieve reasonable outcomes. International institutions that focus on climate or development need to support these efforts and use them before funding major new roads or other infrastructure investments.

For more detail, see "Limiting Cropland Expansion to Lands with Low Environmental Opportunity Costs," a working paper supporting this World Resources Report available at www.SustainableFoodFuture.org.

CHAPTER 20

MENU ITEM: REFOREST ABANDONED, UNPRODUCTIVE, AND LIBERATED AGRICULTURAL LANDS

Some agriculture will inevitably shift from one location to another. Reforestation of abandoned agricultural land or restoration to some other natural vegetation will be required just to maintain net forest and savanna area. However, the potential for global reforestation is sometimes overestimated. Large-scale reforestation to mitigate climate change will be possible only if enough agricultural land is "liberated" through highly successful efforts to slow growth in food demand and boost agricultural productivity.

The Challenge

Many climate mitigation strategies involve sequestering carbon by restoring land now in agricultural use to forest or other natural vegetation. “Forest landscape restoration” typically means the process of restoring ecological functionality by enhancing the number and diversity of trees on the landscape.[108] Restoration can start from completely deforested areas, from degraded forests, or from fragmented forests. It can end up in a variety of land covers and uses, ranging from vast tracts of dense natural forests (which would have the highest standing carbon stocks and biodiversity benefits), to mosaics of wooded areas of land adjacent to agricultural areas, to integrated agroforestry and silvopastoral systems, all the way to mosaics of commercial tree farms and natural forests.

In this chapter, we examine the subset of forest landscape restoration that returns areas of land to dense natural forests, woodlands, and/or woods adjacent to agricultural areas (i.e., reforestation). (Restoration to agroforestry or silvopastoral systems is covered in Chapters 11 and 13.) We focus this chapter still more narrowly on reforestation because forests store more carbon than any other form of terrestrial ecosystem.

Reforestation can occur in one of three ways: spontaneous natural regeneration, in which vegetation regrows without human assistance; assisted natural regeneration, in which land managers reduce obstacles to natural regeneration (e.g., remove fire or grazing animals) and then “let nature take its course”; and active reforestation, in which land managers make significant interventions to reestablish vegetation, such as growing young trees in nurseries and then planting them. Replanting can involve the use of varying mixes of natural species or only one or a few species designed to maximize wood output. But what is the real reforestation opportunity, how should land-planning efforts decide where to reforest, and how can reforestation be advanced?

Many climate studies have found a large potential for reforestation, often in the hundreds of millions of hectares. Examples include broader assessments by the Intergovernmental Panel on Climate Change (IPCC), the “Stern Report” on the costs of climate mitigation, and many original underlying studies.[109] One study even developed a scenario that includes the reforestation of all grazing land that was originally forested before being converted by humans, and would therefore cover large tracts of Europe.[110]

Our analysis is less optimistic, and we explain why we disagree with these high estimates at the end of this chapter (Box 20-1). Ultimately, our analysis is not necessarily at odds with some of the more modest estimates of reforestation potential, but we believe the core condition is that “potentially reforestable” land must not also be needed for ongoing food production. Unless this condition is appreciated and taken into account, reforestation of land in one location will likely lead to more land-clearing in other locations, which undermines its environmental benefit. An alternative poor outcome is that reforestation could lead to reduced food consumption, which undermines its public benefits as well as its long-term political support.

The Opportunity

Using this core criterion, we identify three categories of land that offer real potential for reforestation:

- **Abandoned lands.** Although abandoned agricultural lands will tend to regenerate on their own, there is potential to more actively reforest land that is abandoned as a result of agriculture shifting locations.
- **Agriculturally marginal and unimprovable lands.** These lands generate marginal agricultural output today and have little practical potential for intensification in the future.
- **“Liberated” lands.** These lands occur if demand reduction (Course 1) and productivity improvements (Course 2) result in net reductions in the area of agricultural land.

Improved reforestation of abandoned land

Opportunities exist to enhance the reforestation of agricultural land abandoned as a result of shifting locations of agriculture, even while net deforestation occurs globally. As the satellite image studies discussed in Chapter 17 reveal, abandoned agricultural lands usually regenerate to forest anyway—sometimes naturally and sometimes with the active support of land managers and government. By around 1900, the East Coast of the United

States was largely deforested, but it now is home to extensive areas of forest; the same is true for large parts of western Europe. Although most of this land reforested naturally, the United States actively supported reforestation through the Civilian Conservation Corps during the Great Depression of the 1930s. Between the mid-1950s and 1970, South Korea invested massively in reforestation, raising the country's forest cover levels from 35 percent to 64 percent.[111] The Chinese government reports that since 1991 it has spent $47 billion to plant trees on 28 Mha of formerly marginal agricultural land.[112] Notwithstanding these efforts, opportunities exist to improve the quality of this reforestation both to store more carbon and to support more biodiversity and ecosystem services—in line with the goals of the broad field of restoration ecology.

As just a single illustration, researchers have shown that planting leguminous trees in abandoned fields of Brazil's Atlantic Forest region dramatically increases the rates of biomass growth and enables other, more varied trees to grow as well.[113] Governments now often support reforestation of abandoned agricultural land, but they typically focus on plantation forests, often using a single fast-growing commercial tree species. These kinds of trees are better suited to meet demands for timber products and therefore also earn a more rapid economic return. However, they are less capable of storing carbon, have limited biodiversity when compared to natural ecosystems, and are more prone to risks of fire, storm damage, and pest damage.[114] For example, a study of China's reforestation program in Sichuan province estimated that the planted forests, typically monocultures, had a dramatically lower bird and bee diversity than even the croplands they replaced.[115]

In at least some situations, planting more diverse, native, and relatively slow-growing species provides a realistic economic option, potentially producing comparable or only slightly lower economic returns. In these cases, even modest government interest in biodiversity would warrant reforestation of higher quality. Even for plantations, one study in China has shown that just mixing blocks of two to five different plantation forest types results in substantially more diverse bird populations, with no reduction in economic returns.[116]

Because agriculture is likely to continue to shift locations both within countries and around the globe—at least to some extent—the shifting will likely continue to lead to carbon and biodiversity losses unless governments adopt more policies to establish more natural forests on abandoned agricultural lands.

Marginal lands with little intensification potential

Reforestation opportunities exist on agricultural lands that are producing only limited quantities of food today and whose potential for improved food production in future is low. Steeply sloped grazing land often falls into this category; examples include some of the pasturelands in Brazil's Atlantic Forest region. These hilly lands produce only around 30 kg of beef per hectare per year, which contrasts with the potential to produce around 150–200 kg/ha of beef on well-managed grazing land.[117] Yet the steep slopes make impractical the critical pasture intensification options, which rely on mechanized plantings. In contexts like this, an analysis of the trade-offs between cattle intensification and reforestation would support reforestation. Little-used, drained peatlands represent another prominent example of lands with good restoration potential. Peatlands are so significant globally that we address them separately in the next chapter. We do not know how many hectares of agricultural land truly qualify as "marginal lands with little intensification potential" because no one has yet done the right kind of analysis at this scale.

Reforesting even low-yield agricultural land has some potential to lead to land-clearing elsewhere, although it is less risky than taking high-yielding lands out of production. Taking full advantage of this opportunity therefore requires some additional yield gains on existing agricultural lands or equitable demand reductions.

Reforesting lands "liberated" by yield gains and sustainable demand strategies

Land might be liberated for potential reforestation if the strategies to moderate growth in food demand and/or increase crop and livestock yields achieve sufficient success to result in net global reductions in agricultural land area. Although we have described how challenging such goals are, some of our combined scenarios of multiple menu items would in effect achieve net agricultural land reductions. We provide quantitative estimates of their potential in hectares and associated reductions in GHG emissions in the penultimate section of this report "The Complete Menu: Creating a Sustainable Food Future."

Overall, properly recognizing the limitations that food production imposes on reforestation highlights some important lessons. One is that reforestation at scale requires reducing the need for agricultural land first while protecting other natural areas from conversion. Another is that, precisely because there will probably be only limited areas where reforestation is the best use of agricultural land, those opportunities need to be exploited.

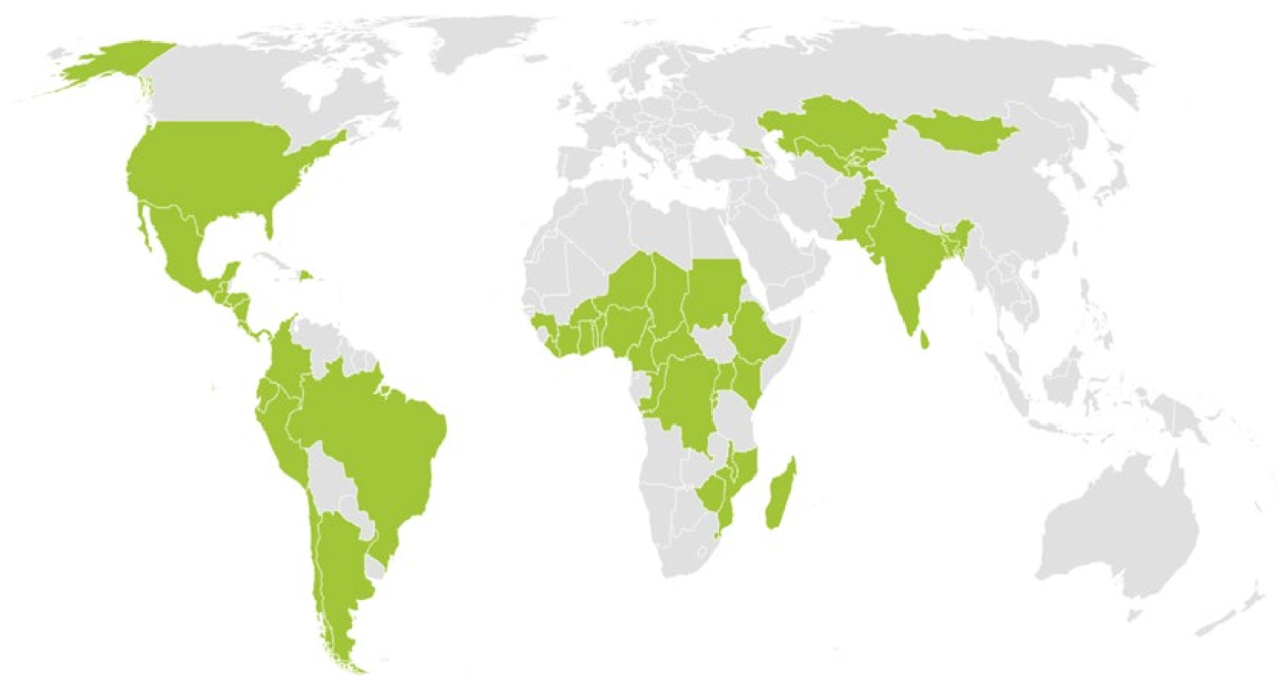
Recommended Strategies

Forest landscape restoration is increasingly prominent on the global agenda. Under the Bonn Challenge—a global effort to bring 350 Mha into restoration by 2030—57 national and subnational actors have thus far committed to restore 170 Mha (Figure 20-1).[118] More than 100 countries have included restoration in their nationally determined contributions to the Paris Agreement.

Some funding has also emerged. The World Bank is investing $1 billion in restoration projects between 2015 and 2030 in Africa, and more than $2 billion in private finance has been pledged under Initiative 20x20 in Latin America.

Other reports have provided useful guidance for moving ahead with reforestation,[119] and we focus here on three key recommendations for moving forward.

Figure 20-1 | Bonn Challenge commitments have been made by 57 national and subnational governments (as of February 2019)



Note: Maps are for illustrative purposes and do not imply the expression of any opinion on the part of WRI concerning the legal status of any country or territory, or concerning the delimitation of frontiers or boundaries.
Source: Bonn Challenge (2019).

Properly identify "marginal and unimprovable" agricultural lands for reforestation

In a world that needs both more food and more carbon storage, the only way to increase both is to make more efficient use of land. Focusing on food and carbon storage alone, it makes little sense to remove land from food production if that food production is efficient or could be made efficient. Reforestation and other forms of restoration should in general therefore focus on land with good restoration potential but with low food production and limited realistic potential to improve it. For any particular hectare, how can one know if and when such reforestation or restoration of other natural habitats would be a more efficient use of land?

The challenge is to find a common measure for testing the efficiency of land use when producing different outputs, such as different foods, bioenergy, or forest. Intuitively, in a world that needs (for example) both maize and forest carbon storage, it is obvious that if land can produce a great deal of maize and little forest, it is best used for maize—and vice versa. But how much maize equals how much forest carbon? One approach is to calculate the carbon opportunity cost of using land one way rather than another.

The Carbon Benefits Index[120] provides an example of such an approach based on the assumption that producing a ton of any particular food in one location will avoid the need to clear other land to produce a ton of that same food. As a result, the carbon savings of producing a food on any particular hectare of land is the carbon that would otherwise be lost on average elsewhere to produce the same food. To estimate this "carbon opportunity cost," the index uses the average global loss of carbon from vegetation and soils that has resulted from producing a kilogram of that particular food. Each food—for example, corn, lentils, or chicken—has a particular cost based on the type of land that was cleared to produce it on average globally and the average yield of crop. The index also incorporates differences in production emissions, so that producing a kilogram of a food with fewer production emissions than the global average generates a carbon savings, while producing a kilogram of food with higher than global average emissions generates a carbon cost. In addition, the index counts any increase or loss in carbon on land as a carbon benefit or cost. Overall, the index makes it possible to compare the benefits in terms of total GHG emissions (CO_2e) avoided under the alternative options of generating a ton of any particular food, preserving land as forest, regenerating land as forest or other natural vegetation, or using land for bioenergy.

Using this analysis, for example, reforesting highly sloped, poorly grazed land in the original Atlantic Forest in Brazil produces clear net gains, but the best use of already-cleared land for pasture in the Cerrado would likely be to intensify its pasture production.[121] This index, or something similar, could also be used to identify the most suitable lands to convert to agriculture when agricultural expansion is inevitable—identified in this report as low environmental opportunity cost lands.

Increasing global carbon storage is not the only goal of reforestation. Protecting biodiversity could be reason enough to justify reforestation of some areas, even of productive agricultural lands, as could preventing high levels of erosion or encouraging tourism. Yet for climate purposes, the general principle should be that governments encourage changes in land use from one category to another when doing so would result in a sizeable net percentage increase in global carbon benefits. Mitigating climate change while meeting food needs will require that land-use decisions maximize the output of each hectare of land.

Integrate more native species in reforestation efforts

Although governments have a long history of financially supporting reforestation of abandoned agricultural lands—or lands where declining productivity implies that abandonment will be likely—their efforts have too often favored forest plantations. To achieve a better carbon balance, more biodiversity, and better forest protection from pests, storms, and fires, governments should support more regrowth of native species, as South Korea, among other countries, is now doing.[122]

Actively support farmer-assisted regeneration

Many farms include areas that are unsuitable for food production but where occasional cattle grazing or the spread of fires are enough to block tree regrowth. Farmer-assisted natural regeneration can occur in these conditions if soil, water, and climate are suitable for natural recovery, and if competing productive uses of the land are low. Another requirement is that native source populations for trees exist, for example, tracts of remnant natural forest, or root stocks of native trees.

We suggest that governments create programs to support farmer-assisted regeneration by specifically including regeneration in existing policy efforts:

- **Traditional agricultural loans.** Integrate lines of concessional credit to restore trees on marginal lands (e.g., poor soils, slopes, riparian areas) into traditional loans.
- **Farmer outgrower schemes.** Embed tree restoration in outgrower schemes, which combine multiple restoration success factors in one package: they provide seeds and seedlings, technical assistance, financing, and champions or leadership.
- **Tenure laws.** Reform tenure and titling laws (as discussed in Chapter 35) to assure farmers that, if they regenerate trees, they will be able to benefit from them.

BOX 20-1 | Why Estimates of Reforestation Potential Tend to Be Too Optimistic

Although the potential for reforestation is real and might be further increased with successful efforts to hold down the rate of growth in demand for food and boost yields, reforestation potential today is typically overestimated. Good policymaking depends on understanding why.

The economic costs of reforestation are typically gauged by estimating the costs of using land to plant trees that will sequester carbon. In such an approach, reforestation potential in any of the vast areas of agricultural land that occupy land where forests once existed is just a matter of price.

The most common method to estimate the cost of using land is simply to value land at its rental value and then to add the costs of planting and maintaining trees.[a] Although often incorporated into more elaborate models, the costs of carbon sequestration equal rental value and the annualized value of these other costs divided by the tons of carbon that can be sequestered each year. For example, if the rental value of a hectare of cropland is $100, and it would be possible for trees to remove 10 tons of carbon dioxide per hectare each year[b] then the land-use cost is $10 per ton of carbon dioxide removed. (For simplicity, we ignore planting costs in this example.) So long as people value climate mitigation at $10 per ton, this method would therefore conclude that it is economical to restore forest on this hectare of cropland.

Unfortunately, the rental price of land does not reflect the true cost of both sequestering carbon and meeting all food needs. Rather, the rental value reflects what farmers would pay to use land in one way, compared to the next cheapest market alternative, which includes actions that release carbon or diminish production. For example, one alternative to renting any hectare of land might be that farmers clear another hectare of land instead. Overall, farmers will only pay rent to use existing agricultural land if the cost is less than the cost of producing the same crops by clearing more land. For this reason, the cheaper it is for farmers to clear new land, the lower the rental value of existing agricultural land. Yet clearing other land releases carbon, which undermines the carbon sequestration benefits of reforestation. An irony of using the rental value method is that, the cheaper it is for farmers to clear more land, the more likely they are going to respond to reforesting one hectare of cropland by clearing another, which would reduce—and could eliminate—net gains in carbon storage. For this reason, rental values should not be used to estimate the costs of gaining net carbon sequestration benefits by taking land out of production.

BOX 20-1 | Why Estimates of Reforestation Potential Tend to Be Too Optimistic (continued)

Perhaps worse, rental values also are limited by the ability and willingness of people to pay for food. When land is taken out of production, some consumers will not be able or willing to pay the resulting higher prices for food and food consumption will decline. In fact, the more price-sensitive is food consumption, the lower will be the agricultural rental value. Again, lower rental values do not necessarily reflect a lower cost of restoring forests while still meeting the same food demands but rather may reflect a larger reduction in food consumption.[c]

In summary, while agricultural rental values do reflect the financial cost of restoring a particular hectare of land, they do not reflect the cost of sequestering carbon on a net basis or doing so while still supplying the same global quantity of food.

Removing some land from production may sometimes lead, through higher food prices, to some desirable results, such as reduced consumption by the wealthy of ruminant meat or reduced food loss and waste. But because any such effects occur through generalized increases in food prices, those same higher prices will also reduce food consumption by the poor, and will probably do so disproportionately because the poor are less able to afford higher prices.[d] The higher prices will also encourage farmers to expand crop area. Taking good agricultural land out of production for the purpose of reforestation is not therefore generally either an equitable or effective strategy for reducing undesirable consumption.

Even when underlying models to some extent reflect these issues, their results can easily be taken out of context and therefore fail to explicitly convey the conditions necessary for reforestation. For example, Griscom et al. (2017) suggest that there is potential to reforest millions of hectares of grazing land. They cite two modeling studies to support the proposition that this reforestation would be possible without sacrificing food production. One of these studies[e] assumes that reforestation occurs only on abandoned agricultural land. Although this paper (using the IMAGE model) does not explain why abandoned land becomes available, the land apparently becomes available only between 2050 and 2100. In other IMAGE modeling papers concerning this period, the abandoned land becomes available as a result of assumptions about limited population growth and high rates of yield gains. The other modeling study[f] estimates that the level of additional land-clearing could be reduced at carbon prices up to $100 per ton of carbon dioxide, in part by intensification of grazing systems, and in part by reductions in consumption of livestock products. This second study tries to estimate what would happen if the cost of climate change at different carbon prices were built into all food production and consumption decisions, so that farmers would be taxed to produce beef and other livestock products, people would pay those taxes when they consumed, farmers would also be rewarded for reforesting their land instead of producing food, and other farmers would be persuaded not to clear more forest in response because clearing would be taxed. Thus, the preconditions for reforestation potential in both studies are substantial. In one study, the condition is a net decline in agricultural land. In the other, stringent global policies are enacted to boost yields, protect existing forest, and discourage consumption of livestock products.

In effect, these conditions represent one way in which a global economic model can simulate successful adoption of many of the recommendations of this report to protect natural areas and reduce demand for agricultural land. As such, these estimates only reaffirm that large-scale reforestation depends on successfully implementing the various menu items in this report.

Notes and sources:

a. Examples of such efforts include Benítez et al. (2004) and a special paper prepared for the "Stern Report," published in updated form as Grieg-Gran (2008). In Benítez et al. (2007), the authors excluded more productive cropland but estimated sequestration costs based on the return to other agricultural land. In van Kooten and Sohngen (2007), the authors reviewed a wide range of studies and analyses and, although they did not describe all the studies in depth, none of the studies were described as focusing on the cost of meeting alternative food supplies on other land and instead were described, at most, as focusing on the opportunity cost of land, which we read as involving the economic return to land for alternative uses at present prices. The studies we have been able to analyze that use economic models also often incorporate this error although sometimes not technically using rent but net agricultural return, which is a way of estimating rent. In Sathaye et al. (2011), for example, the agricultural value of a hectare of land is estimated (and very roughly) by the price of the crops that could be grown minus the costs. In Sohngen and Sedjo (2006), the price of agricultural land is fixed at its rental value, which also effectively means the price of a crop reflects (a) the costs of producing it, including by clearing more land, and (b) the willingness or ability of consumers to pay for it. Therefore, the cheaper the supply of new cropland, and the larger the consumer response to prices, the cheaper the price of crops, and the lower the opportunity cost of using land. Economic models can attempt to get at the carbon costs of equilibrium. At a fundamental level, even equilibrium models are estimating net agricultural returns to land. The reason land receives an economic return is only because the cost of producing food on that land is less than the cost of clearing new cropland, growing food on that land, and transporting that food to consumers, or is less than the price consumers are willing and able to pay.

b. That level of carbon dioxide equals 2.7 tons of carbon per hectare per year, which is a reasonable figure for much reforestation.

c. Many economic models in fact estimate a large food reduction effect from diverting agricultural land to other uses, as discussed in our chapter on bioenergy.

d Regmi et al. (2001); Muhammad et al. (2011).

e. Strengers et al. (2008).

f. Havlík et al. (2014).

CHAPTER 21

MENU ITEM: CONSERVE AND RESTORE PEATLANDS

Only a small portion of the world's agricultural land sits atop peat, but these areas have large impacts on climate change—contributing as much as 2 percent of total annual human-caused GHG emissions, according to our calculations. Given this disproportionate impact, a dedicated effort is needed to avoid any further conversion of peatlands to agriculture and to restore some of the world's peatlands that have already been drained for crops or livestock.

The Challenge

According to one estimate, peatlands[123]—the most carbon-rich category of wetlands—occupy around 450 Mha of land, or roughly 3 percent of the ice-free terrestrial land surface, yet they store 450 to 600 gigatons of carbon.[124] This quantity is equal to between 60 and 80 percent of carbon in the atmosphere (and around one-quarter of all the carbon stored in global soils). Peatlands form because they are located in landscapes that retain moisture and thus have almost permanently saturated soils. The water blocks the penetration of oxygen, which is needed by most bacteria to break down biomass and release the carbon in dead plant material back into the air. As a result, peatlands can build up large deposits of carbon, sometimes over tens of thousands of years. Although grasslands and forests are generally believed to stabilize at maximum levels of soil carbon, peatlands, if undisturbed, tend to continue to build carbon in soils indefinitely. In the tropics, peatland carbon accumulation rates can reach 0.4 tons per hectare per year.[125]

Growing crops on peatlands typically requires draining them so that oxygen can penetrate soils and reach plant roots. (Although plants release oxygen when they photosynthesize, they need oxygen to metabolize sugars into energy just like animals, and this oxygen nearly always comes through the roots.) Drainage leads to a release of carbon to the atmosphere because the oxygen stimulates the activity of bacteria and other microorganisms that break down organic matter, and because dry peats are prone to fires, whether naturally occurring or set intentionally. The amount of carbon released and the propensity to lose carbon through fire depends on the depth of the peat, the incidence of drought in the area, and the depth of drainage (the deeper the drainage, the more peat that is exposed to microbial activities or that becomes dry enough to burn).

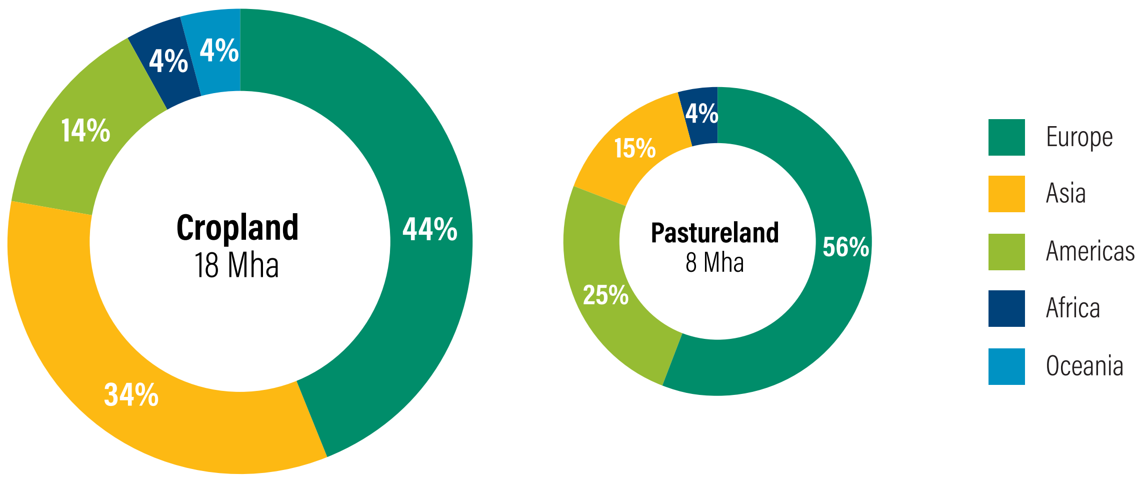
Although two-thirds of peatlands are in climates cold enough to be affected by permafrost, the deepest peat deposits occur in the 13 percent of global peatlands that are located in the tropics, where the combination of high, year-round plant production and saturated soils leads to large annual peat deposits. The best documented, largest expanses of tropical peatlands occur in Southeast Asia, particularly Indonesia and Malaysia, where they have typically supported dense rain forests.[126] In recent decades, these forested peatlands have been subject to large-scale, continuous drainage and clearing for agriculture and forestry. According to one analysis,[127] of the 15.7 Mha of peatlands in Malaysia and Indonesian Sumatra and Kalimantan,[128] only 6 percent (1 Mha) remained in relatively pristine condition as of 2015, and only 40 percent remained in some kind of natural forest (including forests regrowing after full clearing due to forestry activities). In contrast, 50 percent had been converted to use for agriculture or forest plantations. Forested peatland area declined by 1.8 Mha between 2007 and 2015 alone.[129]

Based on our own mapping analysis, we estimate that 20 Mha of cropland, globally, is located on peat; we assume that almost all of this area is probably drained.[130] FAO similarly estimates that 18 Mha of peatlands are both drained and used for cropland, while 8 Mha are drained and used for pasture (Figure 21-1).[131]

Climate assessments originally did not pay much attention to emissions generated by these drained peatlands, but massive fires in Southeast Asian peatlands in 1997, 2007, and 2015 have attracted increasing global attention to the issue. Climate change estimates began to incorporate peatland emissions from this region (Figure 21-2), and more recently they have included estimates of peatland emissions from other countries (Figure 21-3). Amazingly, these tiny fractions of global cropland (roughly 1 percent) and pasture (roughly 0.3 percent) generate emissions typically estimated in the range of 1 gigaton of CO_2e per year, or almost 10 percent of annual emissions from agricultural production and associated land-use change.[132]

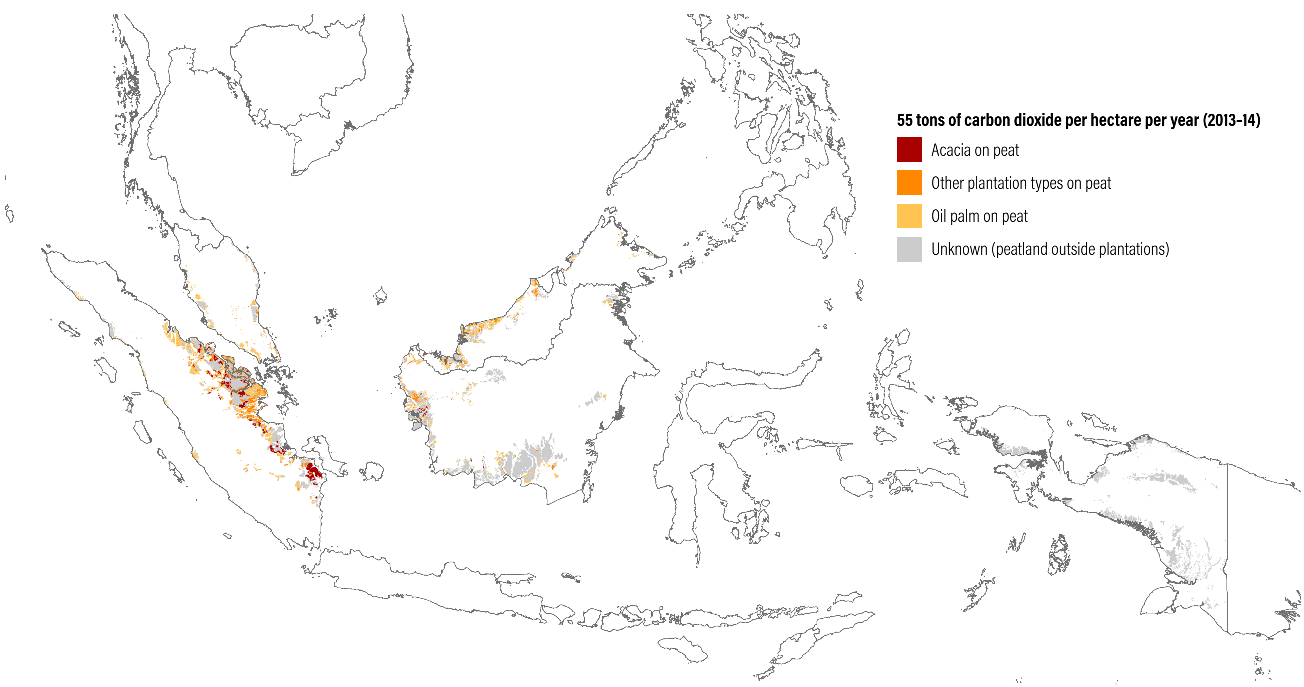
We developed our own estimate to ensure use of the most up-to-date maps of cropland area, peatlands, and emission factors, and to enable a specific focus on peatlands in agricultural use.[133] We estimate ongoing annual emissions at a total of 1,103 Mt CO_2e, of which 863 Mt result from microbial decomposition and 240 Mt (annual average) from fire. These emissions amount to roughly 2 percent of all anthropogenic emissions from all sources, and roughly 9 percent of 2010 emissions related to agriculture. These emissions will continue for decades unless the peatlands are rewetted.

Figure 21-1 | FAO estimates that 26 million hectares of peatlands are drained and used for agriculture



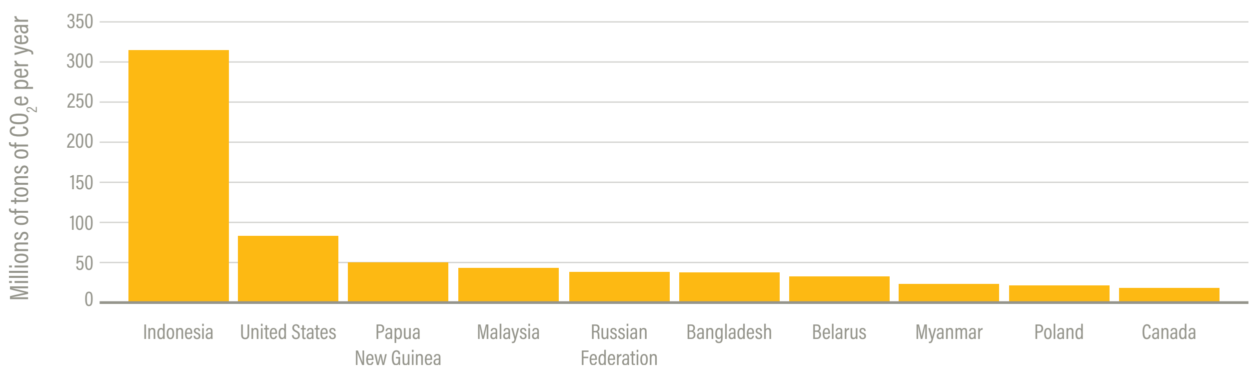
Source: Biancalani and Avagyan (2014), Figure 2.2.

Figure 21-2 | Greenhouse gas emissions from drained peatlands are ongoing in Indonesia and Malaysia



Source: WRI (2017a).

Figure 21-3 | Southeast Asia accounts for the majority of peatland emissions



Note: Graph shows the top 10 countries associated with annual GHG emissions from drained peatlands.
Source: Biancalani and Avagyan (2014), Figure 2.5.

These estimates of emissions from peatlands may be too low if we are underestimating peatland area. Datasets are highly varied because global field mapping is limited, and satellite imagery provides only limited guidance. Researchers recently used a variety of methods to estimate where peatlands should form, backed by some reasonably successful ground validation, and estimated tropical peatlands at 170 Mha, roughly three times the predominant previous estimates.[134] This study estimated much larger peatland areas in Latin America and Africa. Around the same time, a separate group of scientists reported discovery of the world's largest tropical peatland in the heart of the Congo rain forest in central Africa.[135] They estimated that it stores 30 gigatons of carbon, equivalent to roughly 20 years of U.S. fossil fuel emissions. Discoveries of more peatlands may lead to more estimates of drained peatlands and therefore higher estimates of existing emissions. These estimates show the potential for a much greater risk of additional emissions from agricultural expansion in the future. To date, relative land abundance in both Latin America and Africa has reduced the need for investment in drainage of peatlands and other wetlands. But the history of Europe, the United States, and China suggests that as countries develop they tend to drain much of their wetlands for agriculture.

The Opportunity

GHG emissions from peatlands will generally stop if peatlands are rewetted. Going further and restoring forests on naturally forested areas provides additional opportunities for sequestration. The precise techniques for rewetting vary by peatland, but they typically involve blocking drainage ditches and canals. In some situations, restoration may be more complex because roads or dams obstruct movement of water or divert water to other uses. Because peatlands shrink in elevation when drained, one complication typically involves rewetting peatlands to just the right level and avoiding too much flooding, which would prevent vegetation from regrowing. Still, even imprecise rewetting can avoid the ongoing degradation of peat.[136]

Globally, there are many relatively small-scale examples of successful peatland restoration projects. One project rewetted 36,000 ha in Belarus at a 10-year cost estimated at $5 million, or $140 per hectare.[137] A project in China has restored water to tens of thousands of hectares in the 2 Mha of drained peatlands on the Ruoergai (or Zoige) Plateau on the northeastern margin of the Qinghai-Tibet Plateau. Another prominent example in the United States involved the government purchase and rewetting of tens of thousands of hectares of agricultural land in an area that occupied one-quarter of Florida's Everglades. After a protracted lawsuit and political controversy, restoration began as a means of filtering out phosphorus pollution from the remaining agricultural lands before the pollution entered the remaining natural portions of the Everglades.[138]

Although many drained peatlands are in intensive and successful agricultural use, few areas would justify the associated GHG emissions if those emissions were properly valued. For example, one study estimated the value of palm oil at $600 per hectare per year on the most productive oil palm plantations[139]—and oil palm plantations on peat are typically less productive than those on nonpeat soils. But the value of avoiding the likely peatland emissions alone would be $2,750 per hectare per year at $50 per ton of CO_2e,[140] which is well below typical estimates of the carbon costs the world will need to pay to solve climate change.[141] Because oil palm plantations need to be replanted at high cost roughly every 25 years, economically rational opportunities could exist in some situations to rewet peatlands in productive oil palm plantation areas at the natural end of their productive life.

Probably the easier restoration opportunities, politically and economically, are to be found in the millions of hectares of drained peatlands that have some kind of combination of shrub-like vegetation or dispersed, small-scale agriculture. Although no detailed compilation exists, peatland researchers broadly agree that such lands exist.[142] In the main islands of Indonesia, 45 percent of peatlands converted to agriculture as of 2015 were not in plantations but displayed the kind of dispersed cropland, shrubland, and cleared land that is characteristic of smallholder farming. Although there is no detailed analysis of the uses of such lands, the mapping used to identify them indicates that the overall farming intensity is relatively low (at least by comparison with plantations), and people do not typically live on these peatlands in large numbers. More drained peatland is probably included in areas that satellite images identify as shrublands or cleared lands.[143]

One prominent peatland is a roughly 1 Mha area in Central Kalimantan, Indonesia, that the government attempted to convert to rice production via the Mega Rice Project beginning in 1995. Due to poor yields and fires, rice production either never started or was abandoned. The area now exists largely as a drained, cleared, and degrading site. Established in 2008, the Indonesia-Australia Forest Carbon Partnership attempted to restore these peatlands, but it created a variety of local controversies as different communities negotiated the compensation or benefits they would receive for agreeing to restoration. Amid widespread frustration with the lack of progress, Australia abandoned the effort in 2014.[144]

Fortunately, Indonesian President Joko Widodo announced in 2016 a goal to restore 2 Mha of peatland by 2020 (Box 21-1). This announcement came after massive peatland fires in 2015 that, in addition to releasing carbon, caused 500,000 people to be hospitalized. Although this effort is far from fully funded, Indonesia allocated $35 million to peatland restoration in 2017. By 2018, the Peat Restoration Agency reported having rewetted more than 100,000 ha of land, although the standard used involves rewetting only up to 40 centimeters below the surface, so some degradation of soils will continue to occur.[145]

Massive peatland fires in Russia in 2010 also led to an effort with Wetlands International to rewet abandoned peatlands, although its reach has so far been very modest.[146]

Restoring peatlands in Southeast Asia and elsewhere also could generate ongoing economic returns to offset some of the costs.[147] For example, peatlands that naturally supported forests could likely accumulate an amount of carbon from reforestation at rates that could justify substantial carbon payments. Although it would forgo many biodiversity benefits, another option might involve use of rewetted peatlands for agricultural or forest products that could grow well under wet conditions. Some valuable woods, such as European black alder, grow naturally on peatlands. Some European wetland grasses, such as reed canary grass, grow at sufficient yields to contemplate their use for bioenergy. (If produced as part of a strategy to restore peatlands, wetland grasses would generate large climate benefits, although more from the restoration of peatland than from the provision of biomass.) A German project demonstrated that reed fibers could produce fire-resistant boards, while cattail could produce excellent insulation materials. Cultivation of sphagnum moss could produce a valuable additive for horticulture.[148] Another study found that native Indonesian peatland plants could

BOX 21-1 | Indonesia's commitment to peatland restoration

The 2015 fire season was the worst in Indonesia's history, resulting in more than 500,000 people being treated for respiratory illnesses, and causing more than $16 billion in economic losses.[a] Analysts estimate that 2.1 Mha of land and forest burned, resulting in 1.6 Gt CO_2e (more than Japan's annual total emissions) being released from fires that year.[b] The fires occurred largely on drained peatlands converted to oil palm and timber plantations.

To prevent another fire disaster of this scale, President Joko Widodo announced at the UN Framework Convention on Climate Change Conference of the Parties (COP) 21 in Paris the establishment of the Peat Restoration Agency (Badan Restorasi Gambut, or BRG), an agency mandated to restore 2 Mha of peatland by 2020.[c] The president established the BRG through Presidential Regulation No. 1/2016, which lays out a plan to coordinate and accelerate the recovery of Indonesia's critical peatlands.

The BRG's restoration efforts will prioritize seven provinces: Riau, Jambi, South Sumatra, Papua, and West, East, and Central Kalimantan. Out of Indonesia's estimated 12.9 Mha of peatland, 6.7 Mha are degraded and have potential for restoration, while 6.2 Mha are intact with potential for stronger protection. The BRG's first year focused on identifying and mapping the extent and depth of peat domes in four districts in Sumatra and Kalimantan, totaling an area of 644,000 ha. In 2017, the BRG began coordinating and implementing peatland restoration activities in the target districts. The agency is working to mobilize nongovernmental organizations, companies, civil society, and the development community to support its efforts.[d]

Sources:
a. Lamb (2015).
b. Harris et al. (2015).
c. Jong (2015).
d. Wardhana (2016).

produce a wide range of valuable products, including a candlenut that the study found could even exceed the returns for oil palm.[149] Taking advantage of these opportunities may require a coordinated set of investments to support their establishment or marketing, and few have been tested in the real world. But the fact that some plants can grow well even in undrained peatlands suggests that at least some economic opportunities might exist to help support their restoration.

To estimate the potential benefits of peatland restoration, we estimate the GHG emission reductions that would result from restoring 25 percent, 50 percent, and 75 percent of all drained peatlands globally. (The higher number would require some peatlands currently used productively for agroforestry or forest plantations to be rewetted at the time they would otherwise need replanting.) Table 21-1 summarizes the potential GHG emissions benefits of these three scenarios, which would close the overall GHG emissions gap by between 2 and 7 percent.

Recommended Strategies

Pursuing peatland conservation and restoration requires better data, resources, regulation, and political commitment.

Better peatlands data and mapping

As our discussion indicates, mapping of peatland extent is today based on rough estimates because peatlands often cannot be identified by satellite imagery. Mapping relies on national soil surveys, typically conducted for planning agricultural uses, which do not technically identify peatlands but rather identify soils that are characteristic of peatlands. But the quality and effort put into this type of soil mapping is uneven across the world, particularly in more remote areas. This information also does not convey the depth of peat, whether the peatland is presently cropped and drained, or the depth of the drainage. All this information is important to ensure conservation of existing undrained peatlands and identify the optimal restoration opportunities. An international entity or entities will need to step forward and supply the necessary resources and coordination for development of quality and detailed global maps of peatland extent, depth, drainage status, and use.

Resources

First and foremost, restoration requires resources both to fund the physical restoration and, usually, to compensate in some way existing users of the land for their forgone uses. Ideally, this compensation could take the form of assistance to help boost yields of crops outside of peatlands, replacing the forgone food production.

Table 21-1 | Potential of peatland restoration to reduce greenhouse gas emissions

SCENARIO	ANNUAL GHG EMISSIONS FROM PEATLANDS (2010–50) (MT CO_2E)	CHANGE IN SIZE OF GHG EMISSIONS GAP BETWEEN 2050 BASELINE AND 2050 TARGET
Baseline	1,103	
25 percent peatland restoration	827	-2%
50 percent peatland restoration	552	-5%
75 percent peatland restoration	276	-7%

Sources: WRI analysis based on Yu et al. (2010); You et al. (2014); Hiraishi et al. (2014); Biancalani and Avagyan (2014); and van der Werf et al. (2017).

To date, peatland restoration projects have demonstrated technical potential but have been carried out at small scales and in limited contexts. Yet they probably offer one of the least expensive carbon savings of any land-use option, particularly where drained peatlands are now little used. International financial entities aiming to support climate change mitigation, including the Green Climate Fund, the World Bank, and national development assistance agencies, should work together to develop a major global funding initiative on peatland restoration.

Regulation

There is little reason for governments of peat-rich countries or the world's wealthier nations to pay to restore peatlands in one location if farmers can easily shift food production and drain peatlands elsewhere. Governments should therefore establish, and enforce, strong laws protecting peatlands from further drainage or conversion. Indonesia, for example, issued a regulation in 2016 placing a moratorium on clearing peatland until a zoning system for the protection of peatlands and cultivation in peatlands is in place. The moratorium also specified that degraded areas must be restored, although implementation is still at an early stage.[150]

Governments should also consider laws that will not leave the continued use of drained peatlands as assured, regardless of their economic benefits. Although many of those who now benefit from drained peatlands have compelling social arguments for some form of compensation for restoration—preferably as other economic opportunities—emissions from peatlands should not be immune from government regulation any more than other sources of emissions.

Political commitment

Even when drained peatlands are little used, experience indicates that someone is nearly always using them in ways that take advantage of the drainage. Even in the largely abandoned Mega Rice Project area of Indonesia, local people engage in some modest agriculture, and they have used the canals as a means of transportation (for boats or timber), which is easier than trying to move directly through typically saturated peat.[151] Because peatland drainage typically requires networks of drainage ditches, restoration usually proceeds in a series of blocks (e.g., by blocking drainage ditches), affecting multiple people and sometimes multiple communities, and it is hard to get all to agree. Australia's efforts to restore the peatlands of the Mega Rice Project faltered in large part because some groups of people objected to the compensation deals as they unfolded, and occasional negative press emerged based on these objections.

Restoring peatlands, like most other infrastructure projects, has high potential to arouse opposition from some parties, even if the benefits to the public are clear and the project has the support of the vast majority of those directly affected. Efforts to move forward must be sensitive to issues of equity and seek participation and consent but should respect majority support. Projects will not succeed without a strong political commitment to see projects through.

ENDNOTES

1. FAO (2019a).
2. FAO (2019a).
3. Alexandratos and Bruinsma (2012), Table 4.8.
4. GlobAgri-WRR model.
5. To appreciate shifts in locations of agricultural land, an analysis must evaluate how small, specific areas of land change over time, and not simply calculate how the total agricultural land within a country changes over time. The shifts only became possible to analyze once satellites could track locations of all land-use changes over time.
6. Reprinted from Figure 11 of FAO (2012e).
7. Lindquist et al. (2012).
8. Aide et al. (2012) for Latin America; Lark et al. (2015) for U.S.
9. Kuemmerle et al. (2016).
10. Millennium Ecosystem Assessment (2005); Grenyer et al. (2006); Searchinger, Estes, Thornton et al. (2015); Sitch et al. (2015); Wheeler et al. (2016).
11. Aide et al. (2012); Lark et al. (2015).
12. Gibson et al. (2011).
13. West et al. (2010).
14. Hirsch et al. (2004).
15. Aide et al. (2012). The shift in grazing land from dry land in Australia to Latin America is also a good example of this type of shift.
16. Alexandratos and Bruinsma (2012).
17. GlobAgri-WRR model.
18. Van Ittersum et al. (2016).
19. Van Ittersum et al. (2016).
20. Searchinger, Estes, Thornton et al. (2015).
21. FAO (2019a).
22. Bruinsma (2009) predicts an increase in soybean production from 218 Mt in 2006 to 514 Mt in 2050, with a rise in yield from 2.3 t/ha to 3.7 t/ha during that period, leading to an increase in harvested area to 141 Mha. Masuda and Goldsmith (2009) only look out to 2030 and project a "business as usual" scenario in 2030 where 371 Mt of soybeans will be produced on 141 Mha of land.
23. In Latin America, Brazil and Argentina are two of the three largest soybean producers in the world. Africa's potential to produce soybeans is described alternatively in Gasparri et al. (2016) and Searchinger, Estes, Thornton et al. (2015).
24. Soyatech (n.d.).
25. Oil World (2015).
26. UNCTAD (2015).
27. UNCTAD (2015).
28. Pacheco (2012); Greenpeace (2012); Rainforest Foundation UK (2013).
29. For example, see Rainforest Foundation Norway (2012).
30. Corley (2009). Corley's estimate is for palm oil for edible purposes and "traditional" nonedible purposes (which do not include biofuels). Rushing and Lee (2013) project up to an additional 15 Mha of palm oil plantation expansion globally from 2010 or 2012 level (the base year is unclear in the publication) to 2050. The implications of current (2015) low prices for palm oil remain to be seen. For instance, it could delay the timing of expansion until prices rise again. One should note that some oil palm clones are capable of yielding 11 metric tons per hectare (which is way above the current average 4–5 metric tons per hectare), so there is still an upside potential in palm oil yields (D. McLaughlin, personal communication, April 30, 2015). However, getting selected clones to become mainstream is not a foregone conclusion.
31. Laurance et al. (2014); Laurance et al. (2009); Edwards et al. (2014); Busch and Ferretti-Gallon (2017); Seymour and Busch (2016); Vera-Diaz et al. (2009); Fearnside (1982); Chomitz and Gray (1996).
32. Seymour and Busch (2016).
33. Laurance et al. (2009); Laurance et al. (2006). See also summary of articles in Searchinger, Estes, Thornton et al. (2015).
34. Ahmed et al. (2014); Blake et al. (2007).

35 Laporte et al. (2007).

36. Laurance et al. (2014).

37 Ali et al. (2015); Delgado et al. (1998); African Agricultural Development Company (2013); Gollin and Rogerson (2010).

38. Jouanjean (2013).
39. Vera-Diaz et al. (2009)
40. Laurance et al. (2014).
41. Laurance et al. (2015).

42. Laurance et al. (2015).

43. AIIB (2016).

44. Angelsen and Kaimowitz (2001); Ewer et al. (2009); Rudel (2009).

45. Searchinger (2012); Villoria et al. (2014); Hertel et al. (2014).

46. Dorward (2012).

47. If yield increases occur because of increases in other inputs, including chemicals, machinery, or labor, then these nonland costs are likely to increase. This issue is often confused in the literature because studies tend to model effects on land not from increases in yield alone but rather from increases in total factor productivity, which assumes increases in productivity of all inputs and therefore declines in costs of producing crops and, in turn, prices. See, for example, Hertel et al. (2014).

48. Stevenson et al. (2013).

49. Searchinger, Edwards, Mulligan et al. (2015); HLPE (2011); Dorward (2012); Filipski and Covarrubia (2010).

50. Gallett (2010).

51. Hertel et al. (2014).

52. The same yield growth may not precisely influence costs of production in the same way in each country, so this statement is only true roughly and in general.

53. Estimates of these rates of conversion of grasslands to croplands vary but are all in millions of hectares. Lark et al. (2015); WWF (2016).

54. Hoering (2013).

55. Van Ittersum et al. (2016); FAO (2002).

56. Butler (2013).

57. Rosenbarger et al. (2013).

58. Mulyani and Jepson (2013).

59. Recio (2015).

60. Jackson (2015); Nepstad et al. (2014); Assunção et al. (2012); Gibbs et al. (2016).

61. Do Carmo (2017).

62. Wormington (2016).

63. Cameron (2015).

64. Fagan et al. (2013).

65. Murdiyarso et al. (2011); Austin et al. (2012).

66. Palmer (2015).

67. Busch and Ferretti-Gallon (2017). See also Porter-Bolland et al. (2012).

68. Seymour and Busch (2016).

69. Busch and Ferretti-Gallon (2017).

70. Blackman et al. (2017).

71. Busch and Ferretti-Gallon (2017).

72. This paragraph is based on Seymour and Busch (2016); see esp. Chap. 7 for a fuller discussion of how to stop tropical deforestation. See also Colchester et al. (2006).

73. See www.globalforestwatch.org.

74. Seymour and Busch (2016).

75. See, for example, Frank et al. (2017). We do not necessarily endorse the specific findings of this paper, but it does provide one estimate of the likelihood that stopping land-use changes without sufficient, exogenous yield gains will result in an increase in food prices and food insecurity.

76. Data for the following paragraph come from Assunção et al. (2013).

77. Assunção et al. (2013).

78. Annual deforestation rates in Brazilian Amazon with data from INPE (Brazilian National Institute of Space Research) are summarized by Butler (2017).

79. The Brazil story is summarized in Jackson (2015).

80. Jackson (2015).

81. Laurance et al. (2014).

82. Estes, Searchinger, Spiegel, et al. (2016).

83. Climate Focus (2016); Donofrio et al. (2017).

84. Consumer Goods Forum (2014).

85. University of Cambridge, Institute for Sustainability Leadership (2019).

86. University of Cambridge, Institute for Sustainability Leadership (2019). The founding member banks are Barclays, Deutsche Bank, Lloyds Banking Group, Santander, Westpac, BNP Paribas, RBS, and UBS.

87. Fabiani et al. (2010).

88. Gibbs et al. (2015).

89. Gibbs et al. (2015).

90. Soy production in Brazil in 1991 was about 20 million metric tons. In 2005, it was about 56 million metric tons. In 2007, it was about 61 million metric tons. In 2011 and 2013, it was about 75 million metric tons and 82 million metric tons, respectively. Data for 1991 through 2009 are from the U.S. Department of Agriculture, as reported in Boucher et al. (2011). Data for 2011 and 2013 are from USDA (2019).

91. Taylor and Streck (2018).

92. Nepstad et al. (2014).

93. Boyd et al. (2018).

94. Papers using this term in the bioenergy context include Gelfand et al. (2013); Nijsen et al. (2012); and Wicke et al. (2011).

95. Cai et al. (2011).

96. Borras et al. (2011); Baka and Bailis (2014).

97. Federici et al. (2015); Pan et al. (2011); Richter and Houghton (2011).

98. For example, in Palm et al. (2013), an important and oft-cited book focusing on tropical land conversion, the approach recommended focuses on calculations of costs per hectare, not per ton of crop.

99. Nijbroek and Andelman (2016).

100. Estes, Searchinger, Spiegel, et al. (2016).

101. Koh and Ghazoul (2010).

102. *Imperata* grasslands store less than 20 tons of carbon per hectare (tC/ha), compared to more than 100 tC/ha in secondary forests and more than 200 tC/ha in the primary forests of Sumatra and Kalimantan, Indonesia. Figures include both biomass and necromass (Fairhurst et al. 2010).

103. Chapin et al. (2000).

104. Fairhurst and McLaughlin (2009).

105. This figure reflects the area classified as "grassland" by Sarvision's radar-based satellite imagery of Kalimantan in 2010. Unpublished analysis conducted by WRI.

106. Garrity et al. (1997).

107. One study estimates a need for 3 to 7 million hectares of additional oil palm plantations in Indonesia between 2010 and 2020; for links and citations of these figures, see Gingold (2010).

108. Maginnis et al. (2005).

109. See, for example, Stern (2006); Nabuurs et al. (2007); Sathaye et al. (2011); and Sathaye et al. (2005).

110. Griscom et al. (2017).

111. Buckingham and Hanson (2015b).

112. Hua et al. (2016).

113. Siddique et al. (2008).

114. Jactel et al. (2017).

115. Hua et al. (2016). For example, bee diversity in plantations was 5% of that of croplands overall except for eucalyptus.

116. Hua et al. (2016).

117. These estimates of beef production come from Cardoso et al. (2016), which discusses the level of beef production per hectare on pastureland under different forms of management in the Cerrado. Although the Atlantic Forest is a separate region, we estimate that the beef production on sloped pasture in this region is similar to that of the lowest management in the Cerrado, based on personal communications with the authors.

118. See http://www.bonnchallenge.org/commitments.

119. Hanson et al. (2015).

120. Searchinger et al. (2018).

121. Searchinger et al. (2018).

122. Buckingham and Hanson (2015b).

123. Global soil maps tend to map not peat but "organic soils," which are soils with 12% or more soil organic matter. Our mapping of peatlands globally uses organic soils designations.

124. Kolka et al. (2016).

125. Kolka et al. (2016).

126. Morrogh-Bernard et al. (2003); Posa et al. (2011); Sunarto et al. (2012).

127. Mietinnen et al. (2016).

128. For all of Indonesia, and using its own definition, Indonesia's Ministry of Environment and Forestry as of 2017 estimates 24.14 Mha of peatland hydrological units on National Zoning of Peatland Ecosystems.

129. Mietinnen et al. (2016).

130. See full description of methodology for estimating both land areas on peatlands and emissions in note 139.

131. Biancalani and Avagyan (2014).

132. IPCC (2014).

133. Our analysis used the global map of peatland regions from Yu et al. (2010) to calculate the area of cropland on peat soils, the SPAM maps of crop distribution (You et al. 2014), emission factors recommended by the IPCC in a special report on wetlands (Hiraishi et al. 2014), except that we used a single emission factor of 55 tCO_2/ha/yr for both oil palm and acacia plantations based on work by scientists with Wetlands International for reasons described in Biancalani and Avagyan (2014). We also estimated annual average peatland fire emissions based on the Global Fire Emissions Database version 4 (van der Werf et al. 2017).

134. Gumbricht et al. (2017); Joosten et al. (2012).

135. Dargie et al. (2017).

136. Joosten et al. (2012); Biancalani and Avagyan (2014); Rochefort and Andersen (2017); Bonn et al. (2016).

137. Biancalani and Avagyan (2014), Box 7.

138. Grunwald (2018).

139. Abram et al. (2016).

140. This calculation is based on the emission rate of 15 tons of carbon per hectare per year for oil palm in peat based on the emission factors discussed in Biancalani and Avagyan (2014).

141. Cost estimates vary greatly, but $50 is still below the mean, undiscounted estimated mitigation cost in 2030 to hold warming to 2 degrees Celsius based on analysis by the IPCC. See Rogelj et al. (2018), Figure 2.26(a).

142. Joosten et al. (2012).

143. Mietinnen et al. (2016).

144. Davies (2015).

145. Gewin (2018).

146. Wetlands International (n.d.).

147. The examples in this paragraph are all summarized by FAO in Biancalani and Avagyan (2014).

148. Biancalani and Avagyan (2014).

149. Biancalani and Avagyan (2014).

150. See ANTARA News (2016) and Pickup (2017) for more details on Indonesia's Government Regulation no. 57/2016.

151. Nugraha and Jong (2017).

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